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CONSTRUCTION EXPERIENCE USING THE AIRTIGHT DRYWALL APPROACH

with funding provided by

Alberta
DEPARTMENT OF HOUSING
Innovative Housing Grants Program

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CONSTRUCTION EXPERIENCE
USING THE
AIRTIGHT DRYWALL APPROACH

March 1985

Prepared by:

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The views and conclusions expressed and the recomendations made in this report are entirely those of the author and should not be construed as expressing the opinions of the Alberta Department of Housing.

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FOREWORD

This study was made possible with funding provided by the Innovative Housing Grants Program of the Alberta Department of Housing. Originally conceived in 1978, the Program is intended to encourage, sponsor, and assist research and development in the fields of housing, site and subdivision design, energy conservation, site servicing and building product development. Generally, the aims of research funded by the Innovative Housing Grants Program are to reduce housing costs, increase the supply of appropriate housing or improve the utility of performance of dwelling units of subdivisions.

The main purpose of funding these studies is to examine the current issues in the field of housing and to develop innovations which offer improvements. Comments and suggestions regarding the information contained in these reports are welcome.

Innovative ideas come from a wide variety of applicants such as builders, developers, consulting firms, industry associations, municipal governments, educational institutions, non-profit groups and individuals. As the type of project and level of resources vary from applicant to applicant, the resulting documents are also varied.

Please send comments and suggestions or requests for further information to:

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I. EXECUTIVE SUMMARY

The following conclusions can be drawn from the Alberta Airtight Drywall Approach Demonstration Project and the previous and subsequent research work related to that project documented in this report:

1. Providing high degrees of airtightness in new residential construction is within the project management and supervision skills of major tract homebuilders with the use of the Airtight Drywall Approach.

2. When using the Airtight Drywall Approach, the incremental costs of providing high degrees of airtightness in new residential construction to major tract homebuilders are low when trade scheduling is similar to current practice and when the notching of gypsum board sheets around cast-in-place floor joists is not necessary, however, the related costs of providing a controlled ventilation system and aerodynamically uncoupled combustion appliances necessary in airtight houses currently provide a significant financial disincentive to the construction of airtight houses.

3. The related costs of providing controlled ventilation systems and aerodynamically uncoupled combustion appliances have fallen significantly over the past two years and are likely to continue to fall as new products are introduced and competition increases.

4. Combined combustion appliances, that is, where an induced draft, gas fired domestic hot water heater is coupled with a fan-coil, hold further potential for reducing costs associated with aerodynamically uncoupling gas combustion appliances, as they eliminate a combustion source.

5. Concerns regarding a lack of moisture protection when using the Airtight Drywall Approach vis-a-vis the continuous polyethylene wrap do not appear to be valid in light of past and current research and

current demonstrations. In fact, there may be legitimate concerns regarding the reduction of envelope drying due to the use of polyethylene. Building envelope durability may possibly be enhanced by the removal of sheet polyethylene in certain climates.

6. Long term durability of gasket and sealing materials used in the Airtight Drywall Approach remains to be evaluted conclusively. Current indications are positive, however, more study is recommended.

7. The effect of building frame movement, settlement and materials shrinkage on the long term airtighness of the Airtight Drywall Approach remains to be evaluated conclusively. Current experience suggests that differential movements between materials are taken-up by the gasket sealing approach and long term indications are positive, however, more study is recommended.

II. INTRODUCTION

This report documents the construction of three low energy homes built in Edmonton, Alberta during 1984 utilizing an approach to airtightness known as the Airtight Drywall Approach. These three homes were built as a follow-up to an earlier published feasibility study under the Innovative Housing Grants Program and published under the title "A New Approach to Affordable Low Energy House Construction" (ISBN 0-88654-074-7), July 1984. In addition to the documentation of the three houses built in Edmonton, this report also presents evolutionary work on the Airtight Drywall Approach arising out of the experience subsequent to the three Edmonton houses, thus providing a state-of-the-art review of the Airtight Drywall Approach to March, 1985. Relevant background technical information, originally presented in the previously mentioned feasibility study, has been updated as a result of recent research and is contained in the appendices.

III. BACKGROUND

Building envelope airtightness became one of the major techniques employed in the reduction of high residential heating bills brought on by the energy crisis of the 1970's. An airtight building envelope could be shown to significantly reduce or eliminate energy losses due to the mechanism of air exfiltration/infiltration (Besant,Dumont,Schoenau; 1979). In addition, it was recognized that air leakage was a significant moisture transport mechanism that lead to interstitial moisture accumulation and the subsequent deterioration of walls and ceilings (Latta; 1976).

In the early 1980's, airtightening of the building envelope was thought to be a significant factor in reducing wall and attic moisture problems. Unfortunately, modest airtightening of the building envelope in heating climates was often found to lead to an increase in moisture problems rather than the expected reduction. This was due to the interrelated effect that airtightening of the building envelope has with the interior moisture dilution due to natural airchange.

As natural airchange is reduced as a result of building envelope airtightening, interior relative humidity levels rise since the production of moisture within the building enclosure or the transport of moisture into the building enclosure is unchanged. Interior air which exfiltrates after building envelope airtightening has occured, does so at a much higher moisture content at fewer and fewer locations. Where previously, air at a relatively low moisture content exfiltrated over large building envelope surface areas, air now exfiltrated at a much higher moisture content, concentrated at fewer leakage openings leading to localized moisture shocks.

Where sufficient drying potentials did not exist to compensate for these moisture shocks, moisture problems became commonplace. Reductions of wall and attic moisture problems in heating climates occur only when airtightening of the building envelope is comprehensive and coupled with controlled ventilation systems which dilute interior relative humidity levels. Alternatively, moisture can be controled by installing controlled ventilation systems which both dilute interior relative humidity levels and slightly depressurize the building enclosure (See APPENDIX B: MOISTURE MOVEMENT AND CONTROL).

Here was the heart of the problem. Significant degrees of airtightness were desired for both energy conservation reasons and as a method of controlling and possibly eliminating interstitial moisture problems. In fact, airtightness and airtightening strategies were heavily promoted by governmental policy and regulatory agencies and some building codes. The strategy promoted by authorities having jurisdiction and other agencies to achieve the required degrees of building envelope airtightness was the use of a sealed, continuous or integral polyethylene film air/vapour barrier. This approach can be shown to have a number of weaknesses (See APPENDIX A: CONCERNS ABOUT THE USE OF POLYETHYLENE FILM IN RESIDENTIAL CONSTRUCTION). As such, alternative strategies were required which could achieve building envelope airtightness meeting the requirements of air barriers and which are cost effective and capable of being employed by the residential construction industry.

The development of the Airtight Drywall Approach (ADA) as a strategy to achieve building envelope airtightness was, similar to the evolution of polyethylene film as an air barrier, a result of the concerns of the cost of heating energy resulting from air leakage as well as moisture impacts on the durability of the building enclosure. However, the historical beginnings of the Airtight Drywall Approach predate the use of polyethylene as an air barrier by almost a decade. The recent recognition of the inadequacies of polyethylene films as air barriers has simply accelerated the development of the Airtight Drywall Approach rather than be responsible for its origins.

The origins of the Airtight Drywall Approach lie with the Mark VII Experimental House built in 1971 by the Housing and Urban Development Association of Canada (now called the Canadian Home Builders'

Association). This house utilized 10 mm (3/8") fir plywood as both an air barrier and a vapour diffusion retarder. The plywood was installed in a continuous manner on the interior of the exterior frame walls. A secondary interior finish of painted gypsum board was installed over the plywood (Kempthorne, Kohli; 1972). The system was uneconomical to build because of the double interior cladding.

In 1981 G.O.Handegord, then affiliated with the Division of Building Research, National Research Council of Canada, proposed a significant modification of the approach used in the Mark VII Experimental House. Handegord proposed using the airtightness properties of gypsum board sheets together with plywood or waferboard strips incorporated in a modified balloon wood framing technique (Handegord; 1984) thereby eliminating the double interior cladding. A modified version of this technique was demonstrated by the author in the construction of nine demonstration houses in Brampton, Ontario during the winter of 1982 and the spring of 1983. These houses exhibited high degrees of airtightness, averaging less than 1 airchange per hour at a 50 Pascal negative pressure differential (Lstiburek; 1983) as tested by the Canadian General Standards Board Standard, "Determination of the Equivalent Leakage Area of Buildings By the Fan Depressurization Method", CAN2-149.10-M84. The plywood or waferboard strips coupled with the modified balloon framing technique employed in these houses was still sufficiently cumbersome and time consuming to render this approach uneconomical.

As a result of the construction of the Brampton houses, the author proposed the elimination of the plywood or waferboard strips and to rely only on the interior gypsum board and existing framing members to achieve building envelope airtightness. This approach was demonstrated by the author in two houses in Ontario in the summer of 1983: the Shelburne House and the Lawrence Park House (Lstiburek; 1983). These two houses were the first houses to be called Airtight Drywall Approach houses.

However, these two houses still employed a modified balloon framing technique and substantial amounts of caulking to achieve low infiltration rates which were felt to be a significant disincentive to the adoption of the approach by the building community.

In an attempt to address these concerns a third house, the London House, was built in the fall of 1983 and was the first to use standard platform framing and gasket materials to replace caulking (Lstiburek; 1983). A further ten houses, similar to the London House, were built in Ottawa in late 1983 and early 1984 as part of a two year moisture research and monitoring project sponsored by the Canada Mortgage and Housing Corporation. Preliminary results of this project are presented in Section V: SUBSEQUENT EVOLUTIONARY DEVELOPMENT OF THE AIRTIGHT DRYWALL APPROACH.

In July, 1984 a feasibility study titled: "A New Approach to Low Energy House Construction" was published by the Alberta Department of Housing summarizing the research and development relating to the Airtight Drywall Approach to that date. In this publication, a proposed second generation approach to the Airtight Drywall Approach was presented (Lstiburek, Lischkoff; 1984), building on the construction experience of the London House as well as the Brampton, Shelburne, and Lawrence Park Houses. This second generation approach was subsequently demonstrated in the construction of three houses in Edmonton, Alberta during the summer of 1984. A detailed discussion of these three houses follows.

IV. ALBERTA AIRTIGHT DRYWALL APPROACH DEMONSTRATION PROJECT

A. Introduction

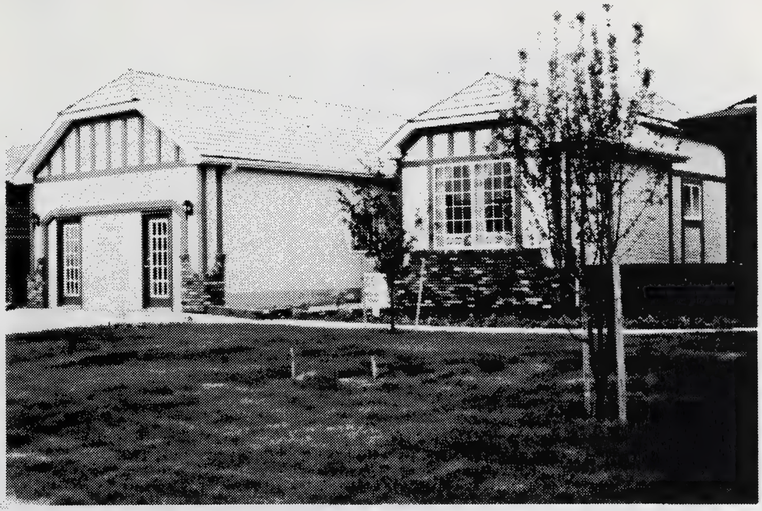
Three houses were built in Edmonton, Alberta in 1984 according to the proposed second generation approach to the Airtight Drywall Approach. These houses were identified as follows:

House	Floor Area	Built
a) Bearspaw Show Home	140 m2 (1506 sq.ft.)	March-May 1984
b) River Ridge Show Home	204 m2 (2206 sq.ft.)	April-July 1984
c) Meadows Show Home	178 m2 (1911 sq.ft.)	June-Oct. 1984

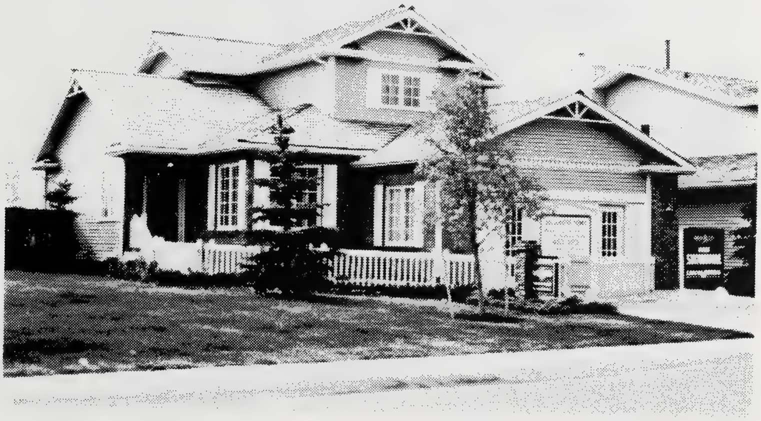
Elevations of these three houses are shown in Photographs 1, 2 and 3 (Pgs. 9, 10) with corresponding floor plans presented in Figures 1, 2 and 3 (Pgs. 11, 12, 13) respectively.

B. Technical Outline of Project

The three houses, in addition to demonstrating the Airtight Drywall Approach concept, were designed using the R-2000 standards of Energy, Mines and Resources Canada as a guide. The Bearspaw and River Ridge Show Homes met the R-2000 standards. The Meadows Show Home did not, as it did not utilize any form of heat recovery on ventilation (had an ATAHE or other heat recovery device been installed, it would have also met the R-2000 standards).



Photograph 1
Bearspaw Show Home



Photograph 2
River Ridge Show Home

Photograph 3
Meadows Show Home

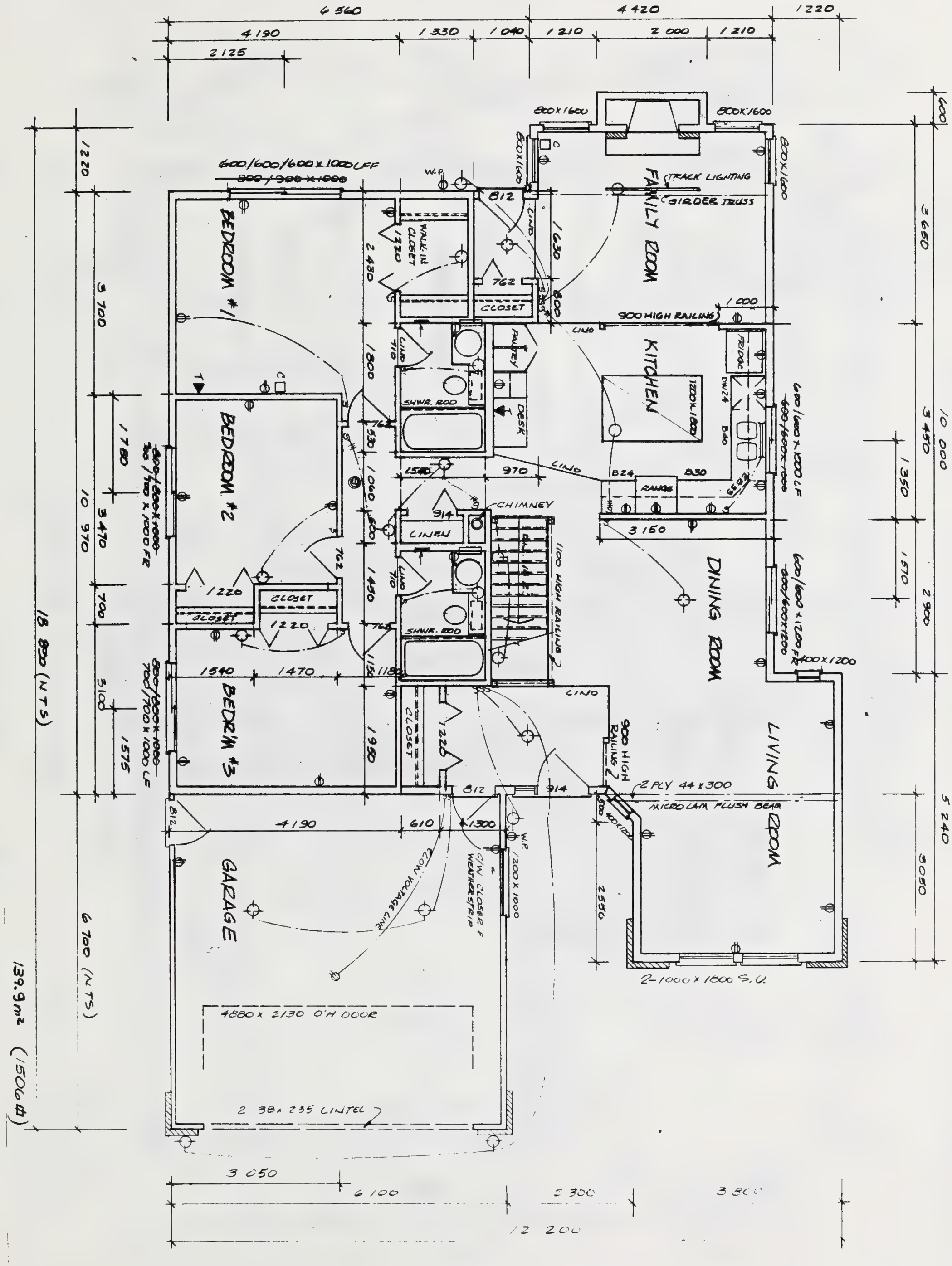


Figure 1: Floor Plan - Bearspaw Show Home

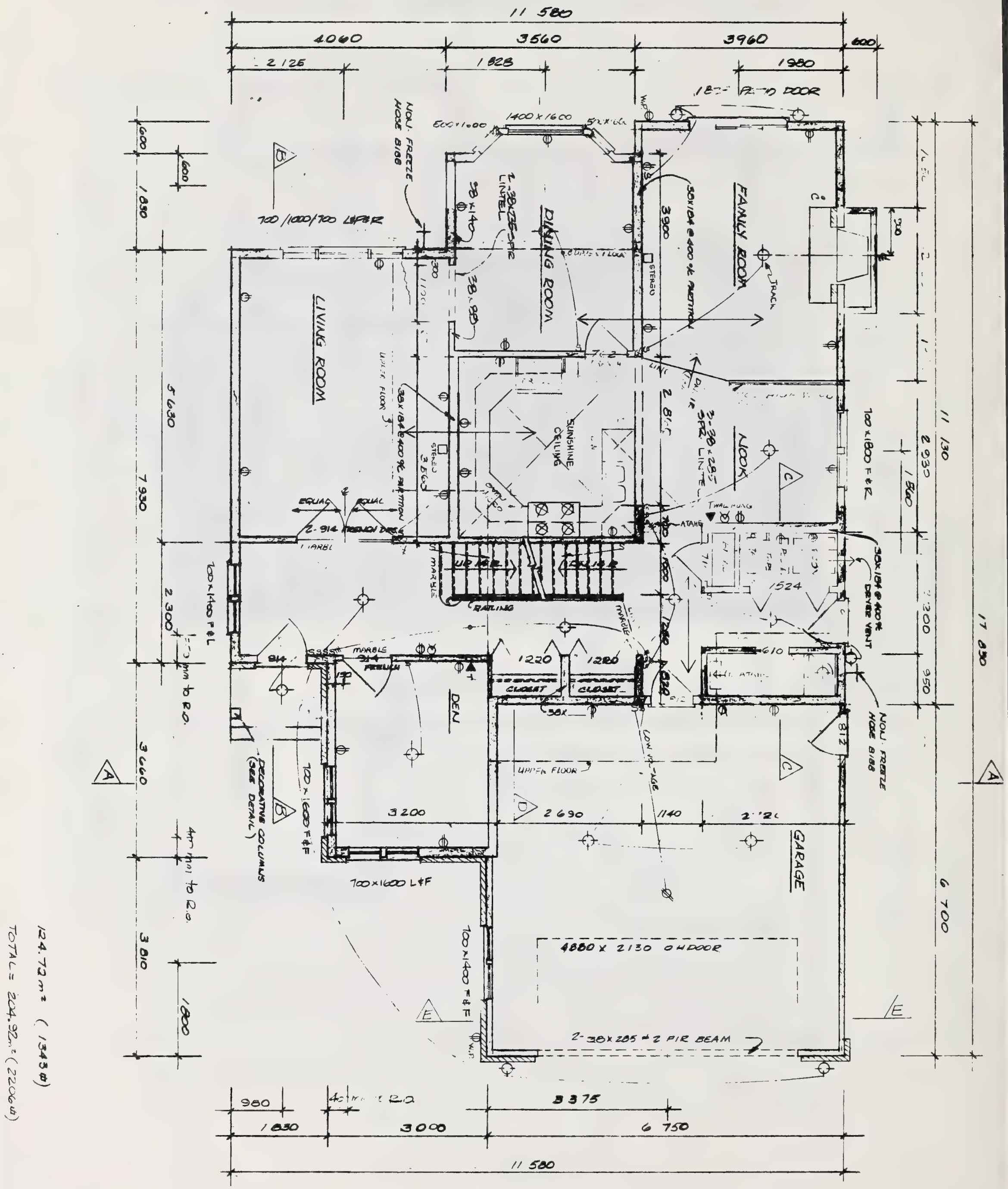


Figure 2: Floor Plan - River Ridge Show Home

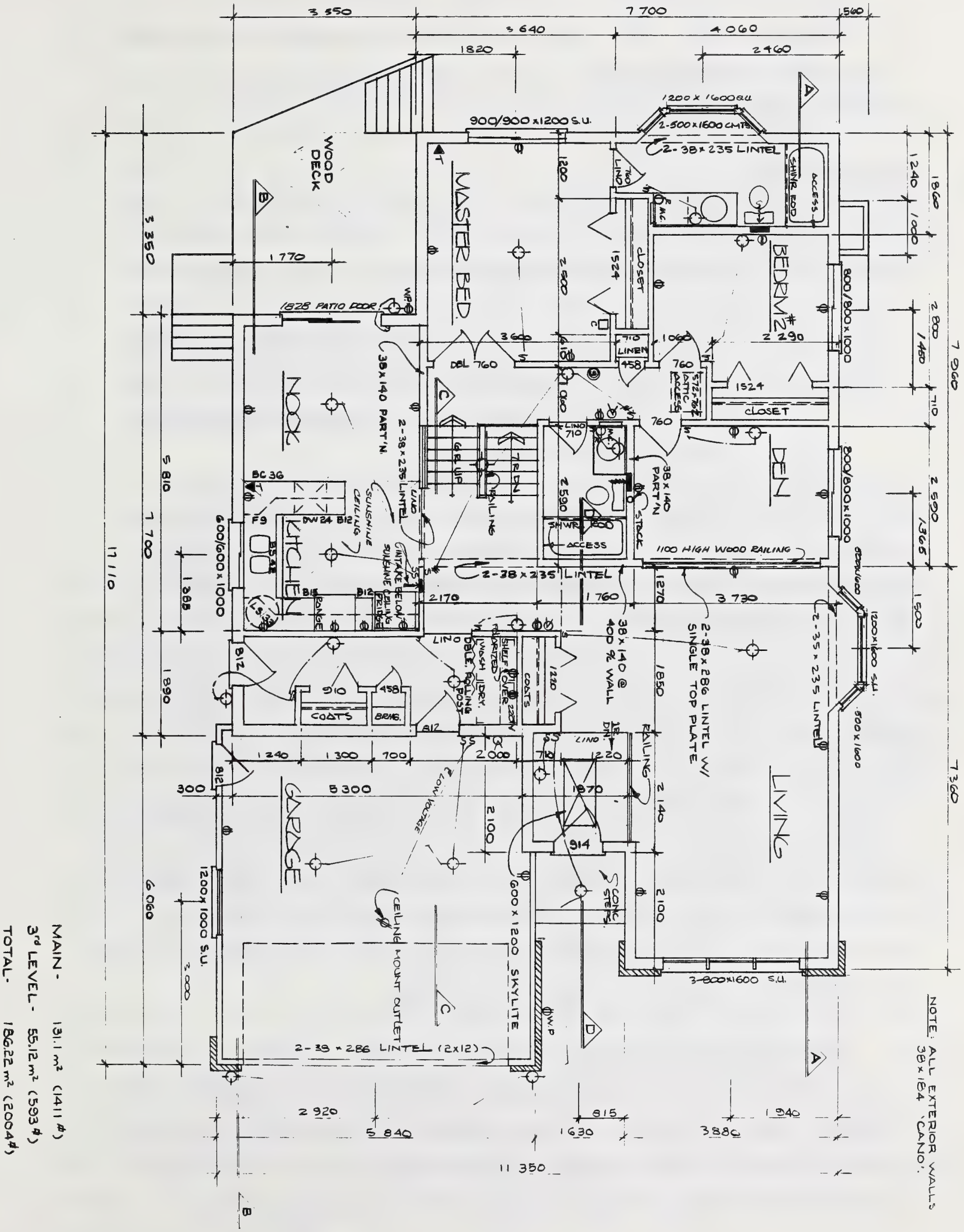


Figure 3: Floor Plan - Meadows Show Home

Briefly, technical requirements were as follows:

1. Energy Budget: The maximum amount of energy to be used for space heating for the three unit types was based on the following formula:

Maximum Space
Heating Consumption = (5 kWh/m2 + (45 kWh/m2 x DD/6000)) x EFA
for a House (kWh)

where: DD = annual Celsius degree-days for the location

EFA = the heated volume of the house in cubic metres calculated from interior dimensions divided by 2.5 metres to arrive at the equivalent floor area in square metres.

The HOTCAN computer program was used to verify design compliance with the energy budget (APPENDIX F: COMPUTER SIMULATIONS FROM ALBERTA AIRTIGHT DRYWALL APPROACH DEMONSTRATION PROJECT).

2. Airtightness: Each house was constructed sufficiently tight in order to meet the requirements of 1.5 air changes per hour (ach) or less at a pressure differential of 50 Pascals. Each house was tested as per the Canadian General Standard Board's Standard for the Determination of the Equivalent Leakage Area of Buildings by the Fan Depressurization Method, CAN2-149.10-M84. For heat loss calculations in the design stage, a natural infiltration/exfiltration rate of 0.05 ach was assumed.

3. Mechanical Ventilation: There was to be a minimum of 0.5 air changes per hour ventilating CAPABILITY (emphasis by author) that was to be provided and controlled by mechanical means. Where heat recovery equipment was used, a maximum efficiency of 50 percent was assumed for design purposes.

4. Wall Construction: Walls were constructed to have a thermal resistance equal to or greater than RSI 3.5 (R-20).

5. All combustion appliances were aerodynamically uncoupled from the building enclosure. Sealed furnace rooms were not used.

6. Temperature Swings: Each house was constructed such that temperature swings within the building's livable area were limited to 5.5 Celsius degrees(10 Fahrenheit degrees). Normal indoor tempertures were defined as 21 degrees Celcius (70 degrees Fahrenheit) for living spaces and 18 degrees Celcius (65 degrees Fahrenheit) for basement spaces.

7. Design combinations which met these technical criteria and the Alberta Building Code were used.

The building envelopes of the three houses were constructed with an air barrier as described in APPENDIX A: CONCERNS ABOUT THE USE OF POLYETHYLENE FILM IN RESIDENTIAL CONSTRUCTION. The air barrier was the interior cladding or gypsum board installed in a continuous manner and joined with appropriate gasket material to wood framing members and the concrete floor slab in the basement. No polyethylene film was used anywhere as part of the air barrier system.

Some simplified wood framing techniques were incorporated including: nail-on window headers which eliminated many of the short studs or cripples prevalent in standard framing.

Innovative heating and ventilating strategies were also demonstrated including a multiple inlet fresh air supply and distribution system coupled with a fan-coil system attached to an induced draft gas domestic hot water heater. However, in the latter system, back-up heat was required due to code requirements and the large heat demand of the house involved (current hot water heaters are only capable of providing 5 to 6 KW).

C. Documentation of Construction

The three Edmonton ADA houses, in order to achieve significant degrees of airtightness, incorporated the construction details proposed in the previously mentioned feasibility study, "A New Approach to Affordable Low Energy House Construction". These details along with additional construction details developed to deal with previously unencountered building geometries arising out of the construction of the three Edmonton ADA houses will now be discussed.

1. Foundation Details

The footing detail (Figure 4, Pg. 17) utilized dampproofing on the top of the cast concrete footing to provide for a capillary break in addition to the standard dampproofing applied on the exterior of the cast concrete perimeter basement foundation wall. A dampproofing coating was also applied to the interior surface of the concrete basement foundation wall to grade level to act as a vapour diffusion retarder in order to meet local building code requirements.

Considerable disagreement exists regarding the necessity of installing a vapour diffusion retarder in this location as well as the logic of running it only to grade level. The proponents of installing this interior vapour diffusion retarder argue that by stopping it at grade any moisture which may have migrated into the interstitial space between the finished interior gypsum board surface and the concrete perimeter wall will be able to diffuse to the surrounding atmosphere through the exposed concrete above grade level. These same proponents, however, typically have no argument for installing a vapour diffusion retarder in this location in the first place, but they insist that if one is to be installed, it must stop at grade level.

One of the few arguments for installing a vapour diffusion retarder on the interior surface of a concrete perimeter foundation wall is to try to prevent or reduce the migration of the large quantities of moisture found in freshly cast concrete into the interstitial spaces. Presumably this argument implies that if the concrete is allowed to dry before an insulated interior frame wall is installed, then no

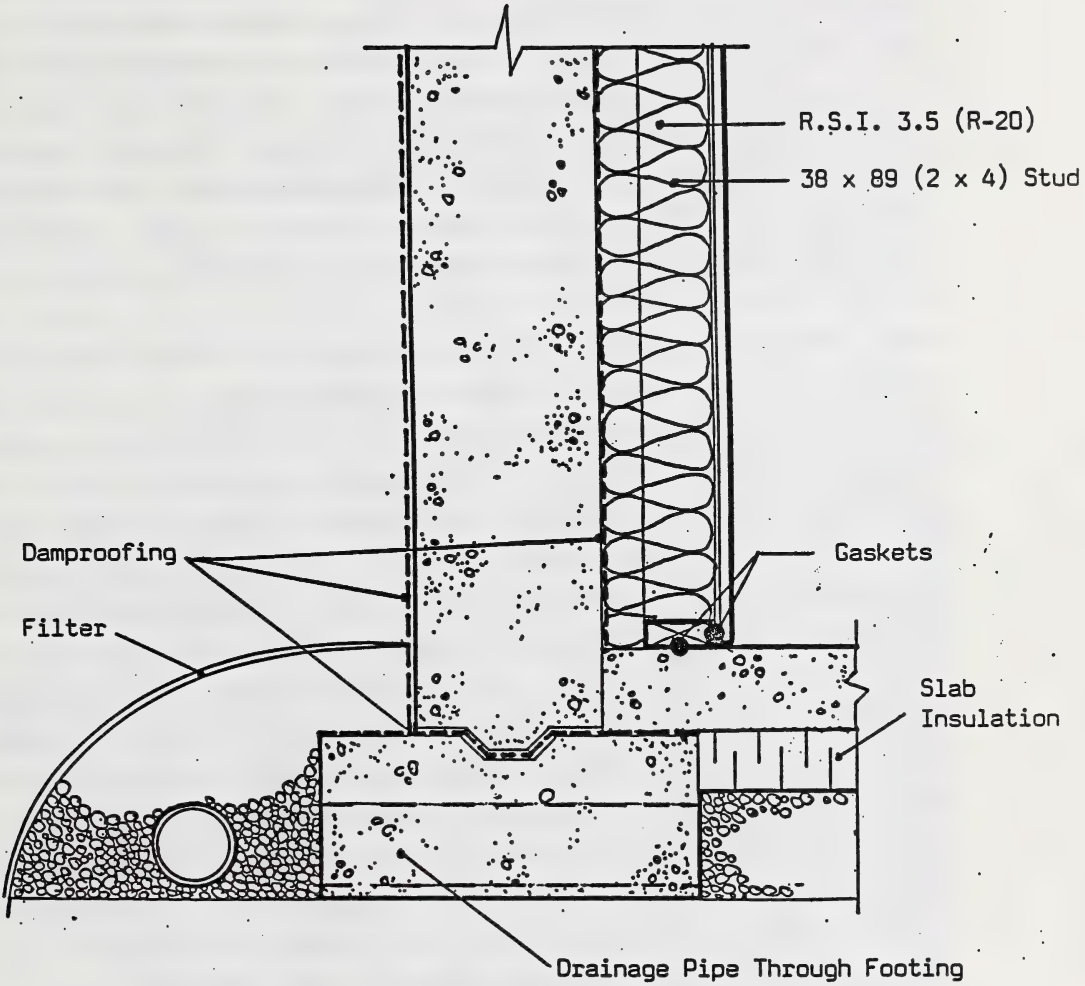


Figure 4: Footing Detail

vapour diffusion retarder is required at this location.

If a vapour diffusion retarder is installed to prevent moisture from migrating into the interstitial space of a perimeter frame wall, then, logic should dictate that the vapour diffusion retarder be installed to the top of the foundation wall. Also, an additional capillary break should presumably be installed at the top of the cast concrete wall between the concrete and the framing materials, thus ensuring that the only drying of the concrete occur to the surrounding atmosphere through the exterior exposed concrete above grade level. Moisture which migrates from the house interior into the interstitial space between the gypsum board surface and the concrete wall will condense on the interior surface of the concrete if its surface temperature is below the dew point. The installation of a vapour diffusion retarder at this location will not prevent this from occuring. The condensation will merely occur on the interior surface of the vapour diffusion retarder instead of directly on the surface of the concrete. This condensed moisture will run down the surface of the concrete (or the surface of the vapour diffusion retarder) to the basement floor slab level. It is unlikely that any appreciable amounts of moisture will diffuse above a vapour diffusion retarder terminated at grade level through the basement concrete to the surrounding atmosphere. It may be appropriate to simply allow this moisture, likely to be in liquid form and located at the floor slab level, to drain through the slab into the granular material typically located below. This strategy was not implemented due to local code restrictions and builder unease, although it was recommended.

2. Crack Initiators for Basement Walls

A strategy which was recommended and adopted was the use of crack initiators to control concrete perimeter foundation wall cracking. This strategy employed the use of prism shaped pieces of forming material inserted into standard forms to in essence pre-crack the concrete foundation wall (Figure 5, Pg. 20). The use of crack initiators induced the concrete to crack at these pre-determined locations rather than elsewhere in a random manner. Since the location of basement wall cracks was now predictable, the cracks could be pre-fixed before backfilling. This pre-fixing was accomplished by the use of a strip of rigid, draining fiberglass insulation, tied into the perimeter drain system. A mastic or sealant was not relied upon exclusively to seal the exterior of such initiated cracks as it was felt that the mastic would dry and eventually crack, leading to potential moisture ingress. The location of crack initiators was determined by the CSA Standard, "Concrete Construction for Small Buildings", which recommends crack initiators spaced at 5 metre (15 ft.) and at stress concentrations such as under basement windows.

3. Air Barrier Detail at Grade

Air barrier continuity at grade, when utilizing ADA with standard platform framing, is typically achieved as described in Figure 6, Pg. 21. However, in Western Canada it is usual to utilize cast-in-place floor joists at grade. As such, the standard approach to ADA at this location was not possible. For the three Edmonton ADA houses, two details were employed to provide air barrier continuity at grade through the cast-in-place subfloor framing when siding or brick cladding was utilized (Figure 7, Pg. 22 and Figure 8, Pg. 23). Central to this strategy was the notching of gypsum board sheets around the floor joists and sealing the resultant seams with a sealant (Figure 9, Pg. 24). This approach provided satisfactory performance with respect to air barrier continuity, but ultimately proved unsatisfactory with respect to time, labour and monetary considerations. It proved to be too time consuming and labour intensive to be practical in the long term. It may also prove not to be durable over the long term due to joist shrinkage. Unfortunately an alternative strategy was not proposed in time to be field evaluated in the Edmonton project. A more acceptable strategy was subsquently developed and is described in SECTION V: SUBSEQUENT EVOLUTIONARY DEVELOPMENT OF THE AIRTIGHT DRYWALL APPROACH.

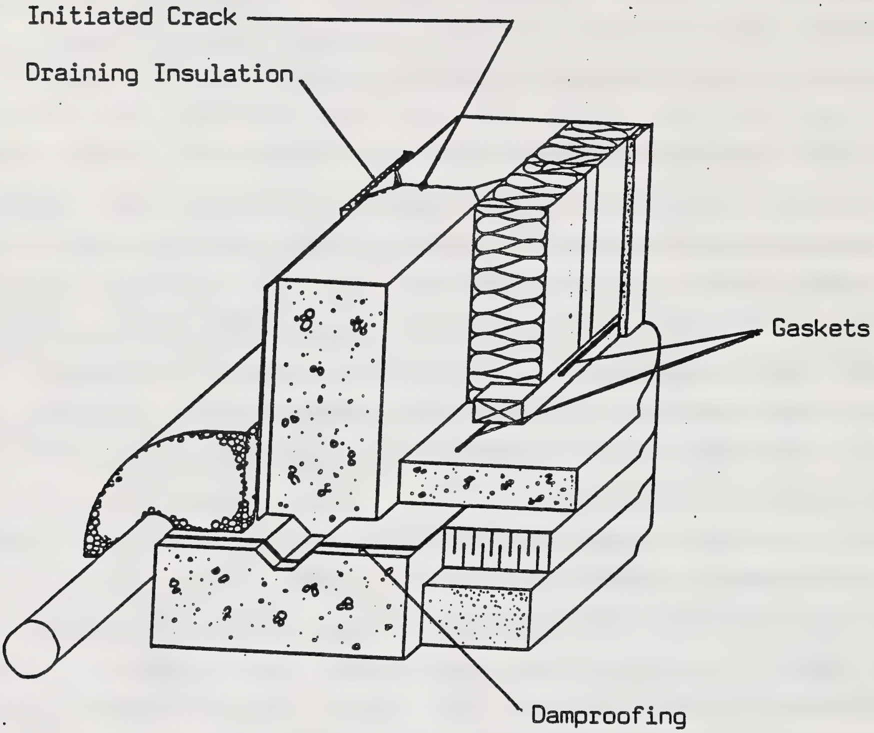


Figure 5: Footing Detail-Crack Initiator

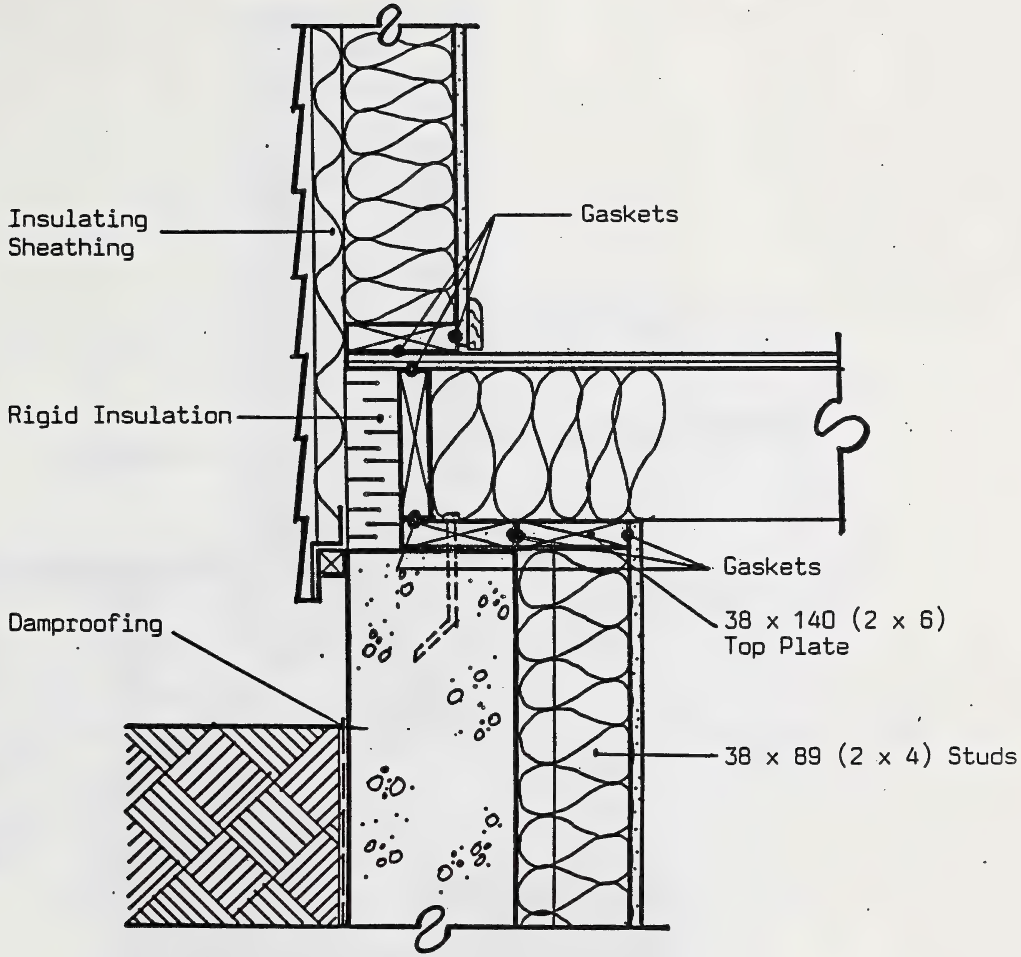


Figure 6: Subfloor at Grade

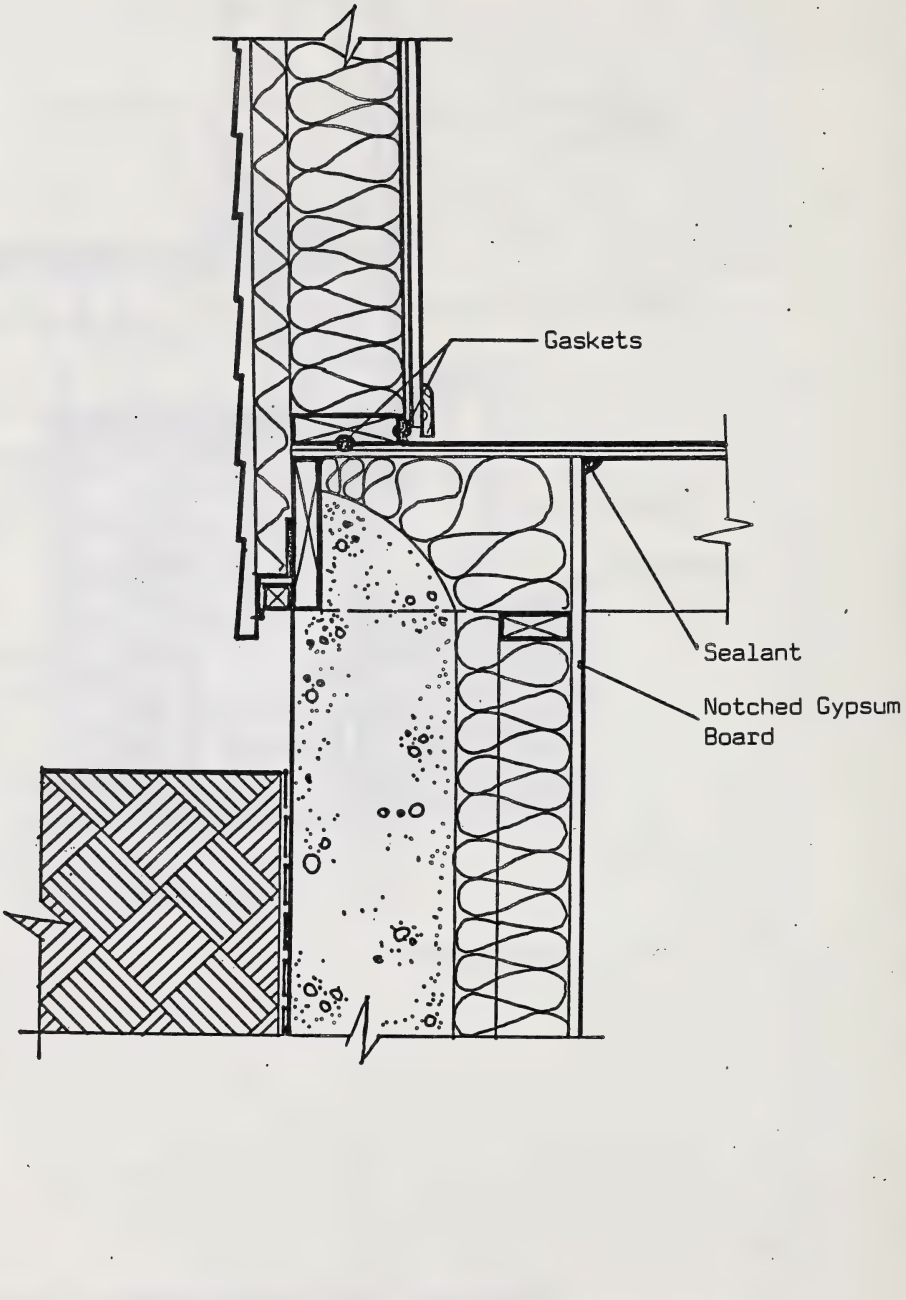


Figure 7: Subfloor at Grade

Cast-in-place Floor Joists

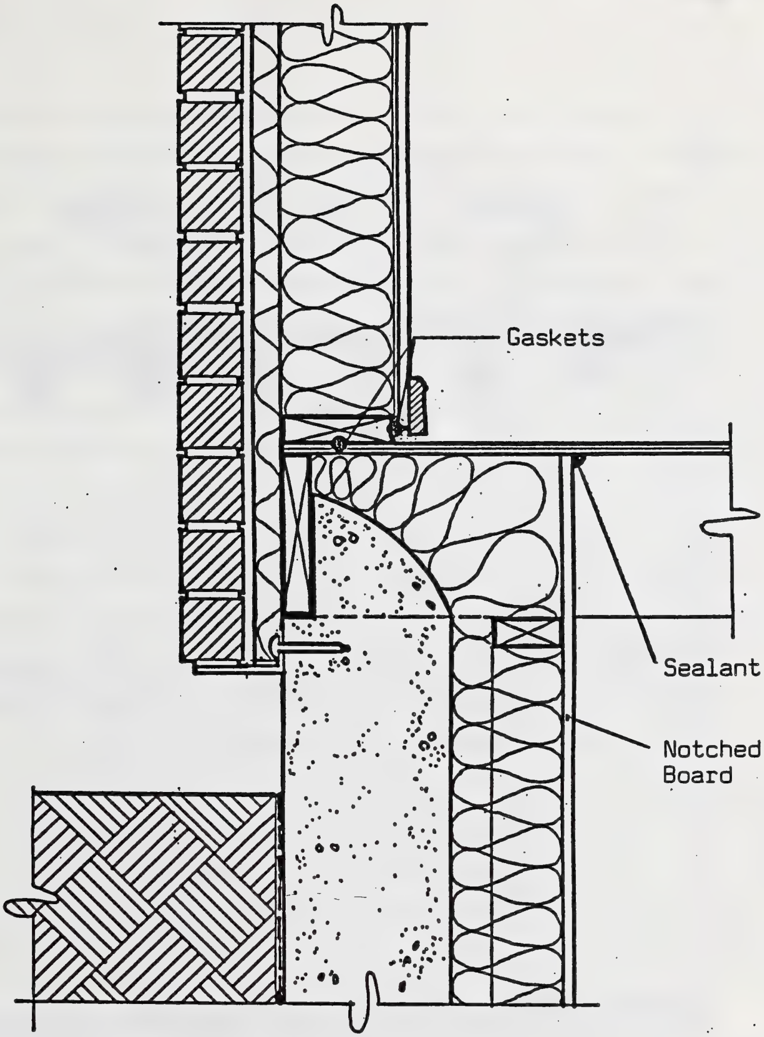


Figure 8: Subfloor at Grade
Cast-in-place Floor Joists,
Brick Veneer

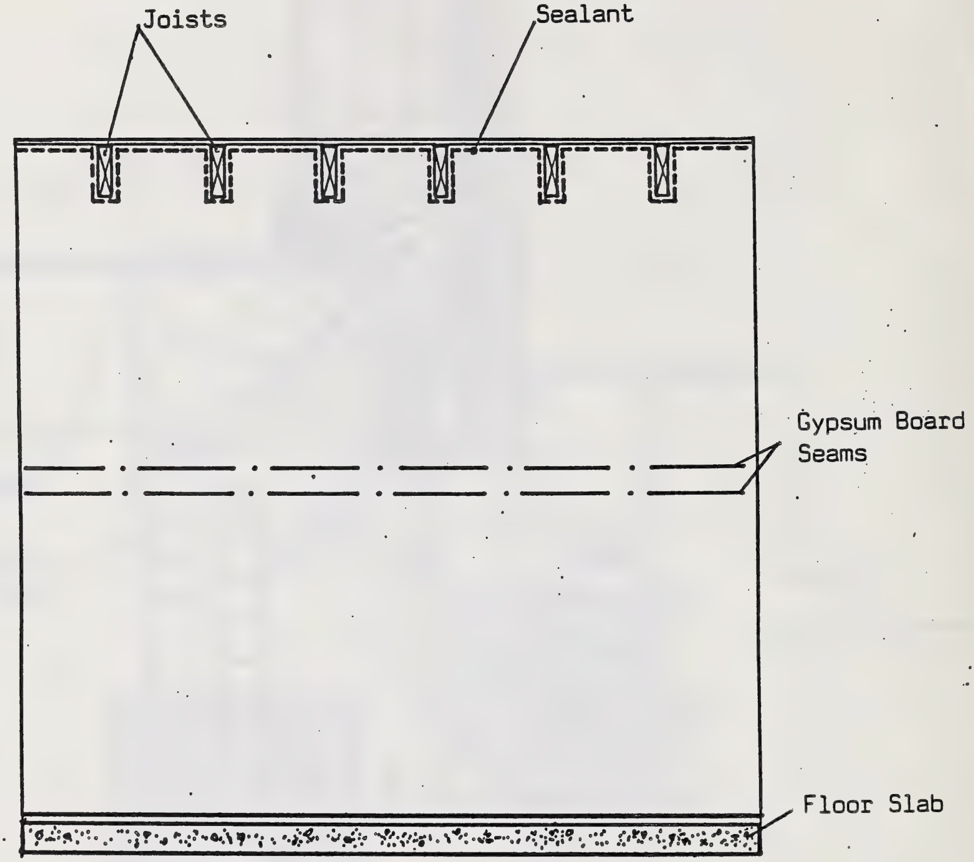


Figure 9: Notched Gypsum Board

4. Air Barrier at Second Floor

In the two multi-storey Edmonton ADA houses, air barrier continuity between storeys at subfloors was accomplished as shown in Figure 10, Pg. 26, for standard subfloor framing and as shown in Figure 11, Pg. 27, where floor trusses were employed. The major difference between the two is the use of plywood as a rim joist, (header or band joist) in place of a standard wood joist. This was to compensate for differential shrinkage rates between waferboards, plywoods and floor trusses as compared to typical floor joist material. Floor trusses, which practically do not shrink, are combined with a waferboard or plywood rim joist or header. Standard floor joists, which do shrink as moisture contents decrease, are combined with standard rim joist or header materials which shrink at the same rate. A minor difference to note, between Figure 10, and Figure 11, was the use of a construction adhesive to provide a seal between the top of the plywood rim joist and the plywood subfloor in Figure 11, as opposed to a gasket in this location in Figure 10. A gasket was judged to be too difficult to install in this location. A wide gasket, of rectangular profile (Dow Sil Seal) was used at the bottom of the plywood rim joist in Figure 11, as it would have been too difficult to accurately position a narrow gasket directly under a narrow rim joist. A sealant was not used in this location in order to allow for building frame movement.

5. Air Barrier at Ceiling

Air barrier continuity where exterior perimeter walls met insulated ceilings was provided for as described in Figure 12, Pg. 28. The air barrier is made continuous at this location by virtue of the taped gypsum board joint between the wall gypsum board and the ceiling gypsum board. It should be noted that treated paper baffles were installed between the roof trusses directly in line with and above the exterior perimeter wall top plates. This limits the deleterious effects of wind washing or blow-through in which wind can serve to short-circuit thermal insulation and lead to local chilling of the interior cladding, which often results in high surface relative humidities and attendent mould and mildew growth. It is important to

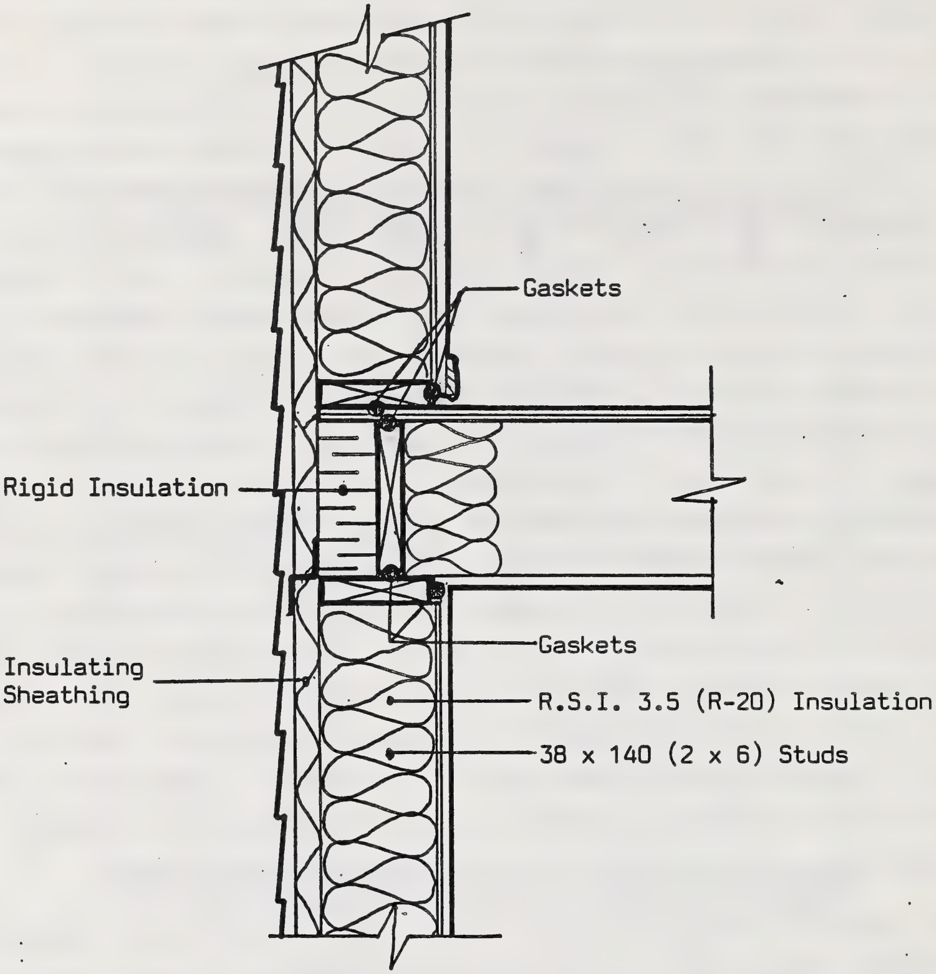


Figure 10: Second Floor Subfloor

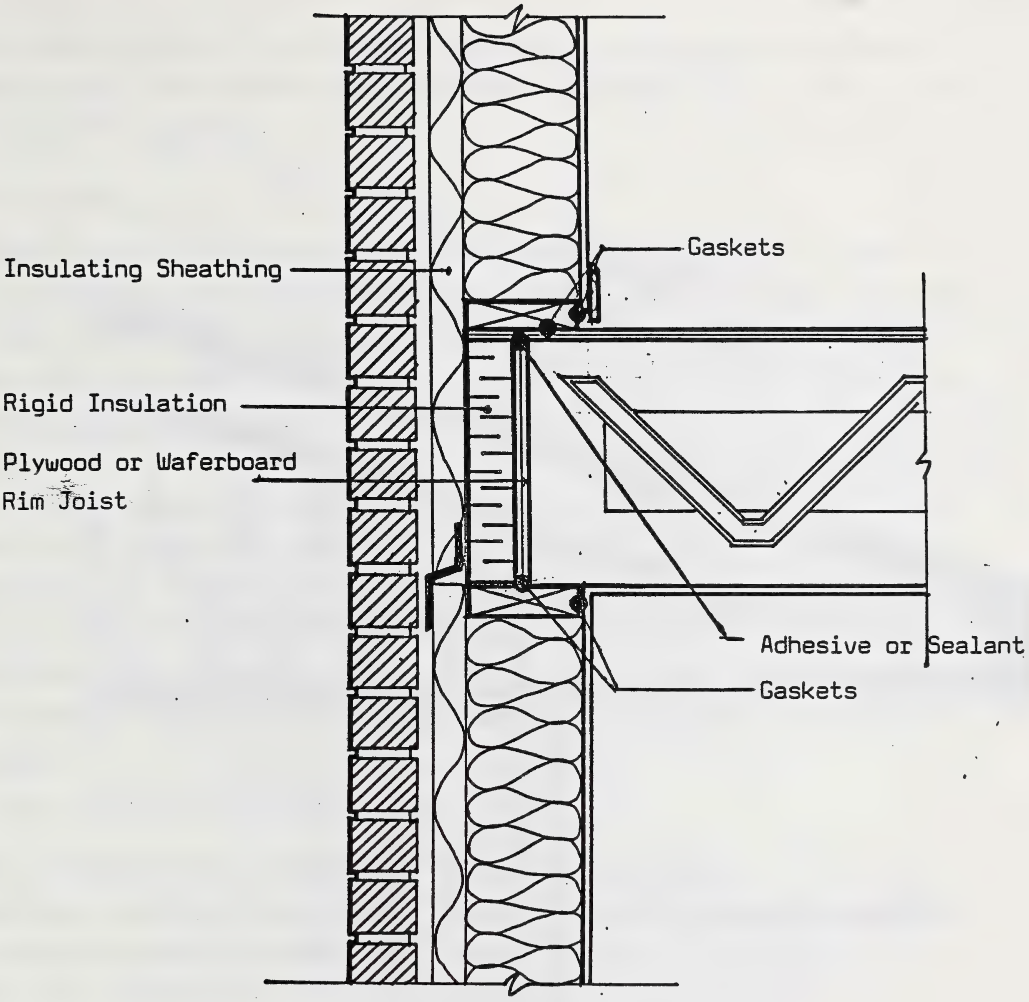


Figure 11: Second Floor Subfloor - Floor Trusses

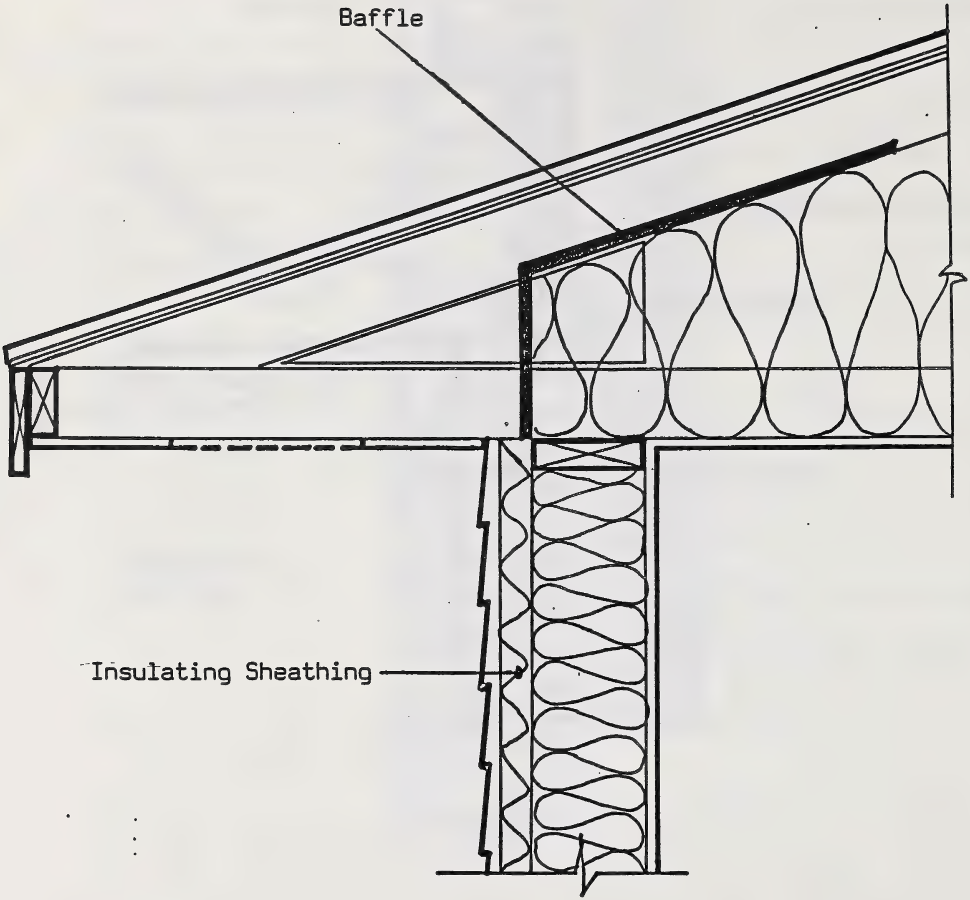


Figure 12: Roof/Ceiling Interface

note that a perfect air barrier located on the interior of an exterior wall will not eliminate mould and mildew formation as it does not prevent wind washing.

6. Windows

Window installation was facilitated as described in Figure 13, Pg. 30, in which the interior gypsum board surface was returned to the window frame and the seam was sealed with an appropriate sealant, typically paintable caulking. A gasket was not utilized here for obvious practical reasons. Where a wood jamb was desired, the detail in Figure 14, Pg. 31, was employed. In this detail the gypsum board is sealed directly to the wood jamb extension with caulking and this seam is hidden with standard trim. For this detail to work in a satisfactory manner, the wood jamb extension must be sealed to the wood window with a continuous bead of adhesive. Windows often come with wood jamb extensions factory installed. In such cases, it should be specified that factory applied adhesives be applied in a continuous manner.

7. Cantilevered Floor Construction

Cantilevered floor construction, typically encountered at second floor subfloors and at bay windows, was facilitated with the use of the construction details presented in Figure 15, Pg. 32 and Figure 16, Pg. 33. In Figure 15, where intersection floor joists crossed over a perimeter exterior wall, wood blocking or blocks of rigid, non-air permeable, insulating sheathing were inserted into the joist spaces and sealed around their edges with caulking to provide for air barrier continuity. The air barrier over the cantilevered portion of the subfloor therefore became the actual subfloor sheathing. Seams in the subfloor sheathing material were therefore sealed with a subfloor adhesive. In Figure 16, where floor joists are aligned parallel to a lower perimeter exterior wall, a floor joist is positioned directly over the lower perimeter exterior wall and gasketed similar to a typical rim joist. Again, the subfloor sheathing was the air barrier over the cantilevered portion of the subfloor with the seams sealed.

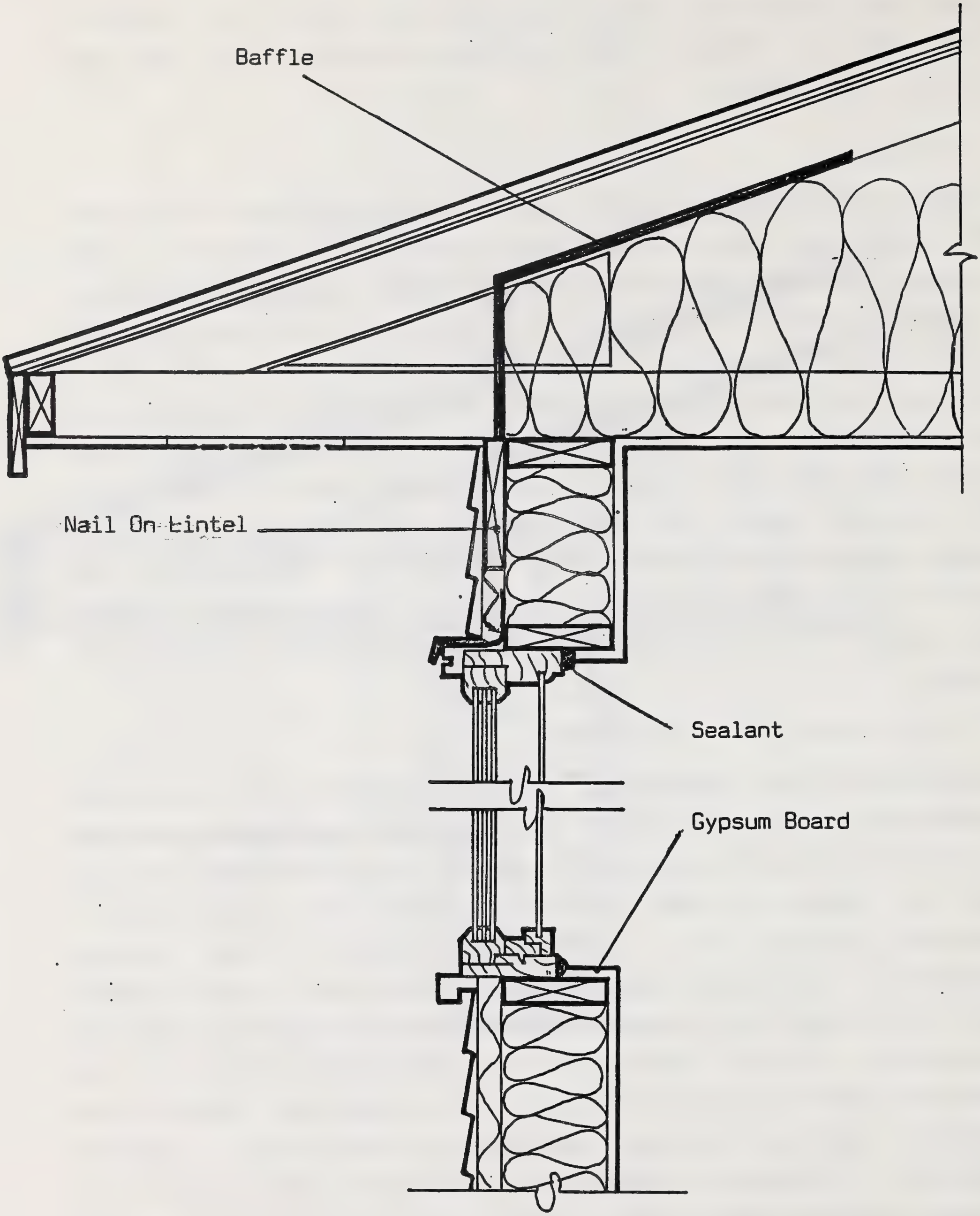


Figure 13: Window Detail - Drywall Return

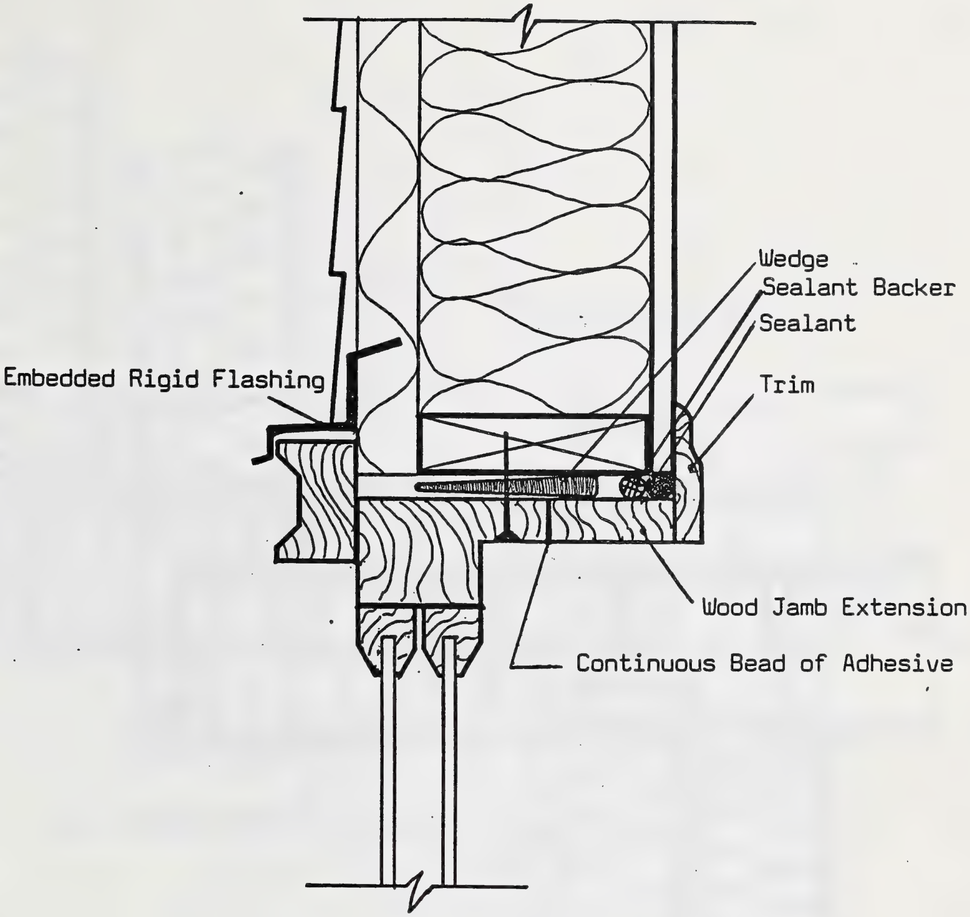


Figure 14: Window Detail - Wood Jamb Extension

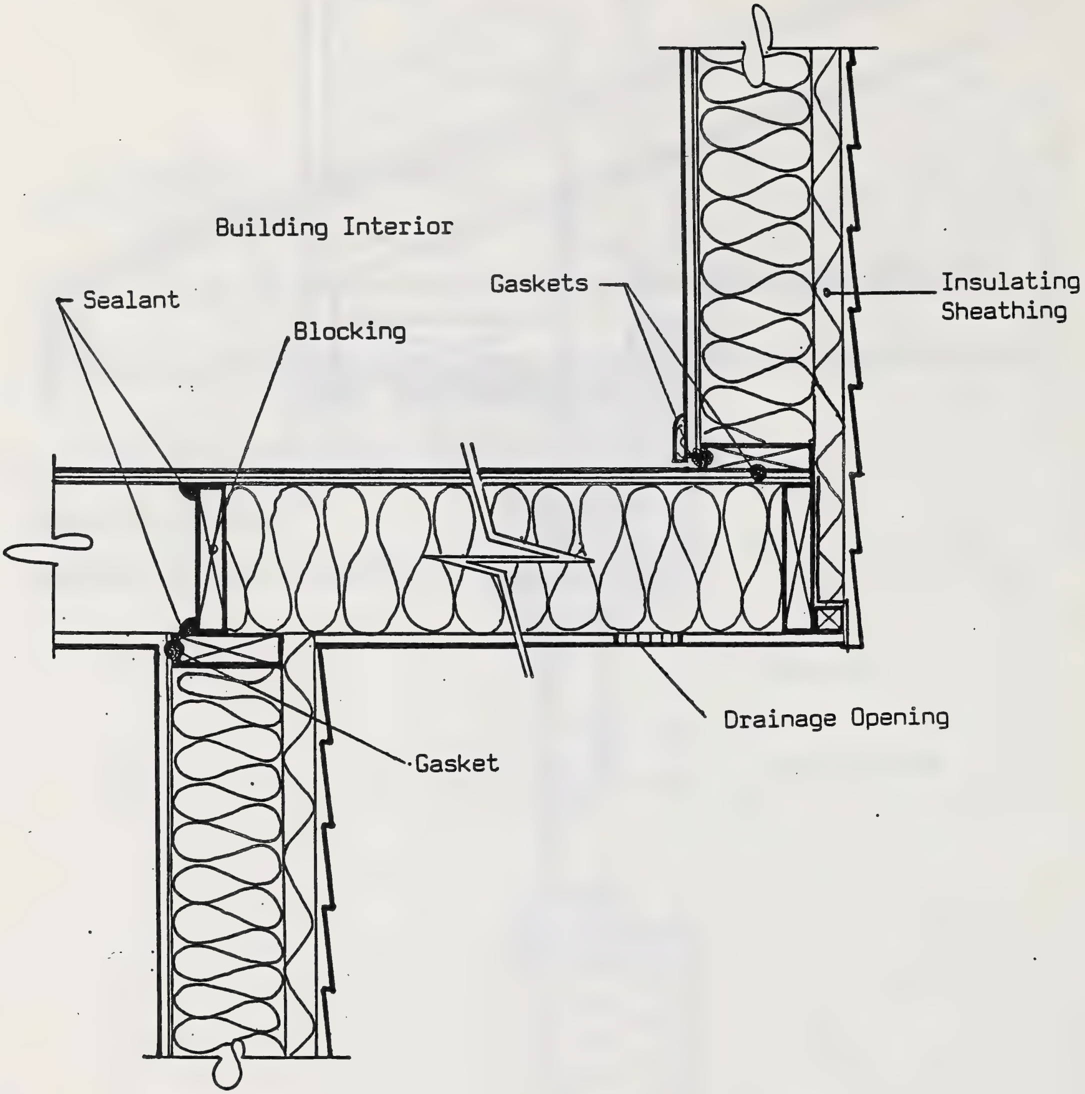


Figure 15: Cantilever Floor - Intersecting Joists

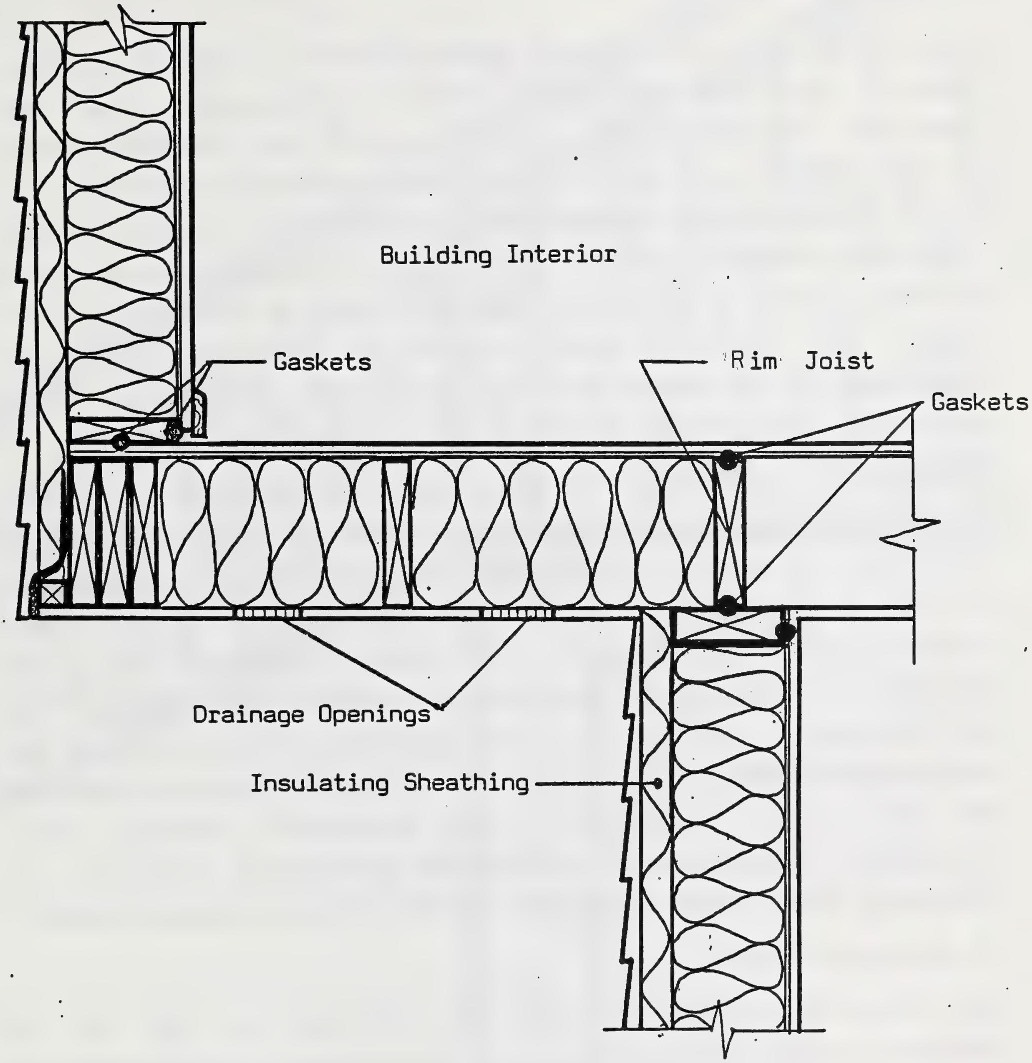


Figure 16: Cantilever Floor - Parallel Joists

8. Interior Partitions

Interior partition walls located under insulated ceilings in the three Edmonton ADA houses were constructed after ceiling gypsum board was installed. This was possible due to the use of roof trusses. However, as the complexity of floor plans and roof construction increased due to the need for client customization, occasional interior load bearing walls under insulated ceilings were required. Air barrier continuity in such a situation was accomplished as detailed in Figure 17, Pg. 35. Gaskets were installed on both sides of the load bearing top plate providing for air barrier continuity between the ceiling gypsum board sheets on either side of the load bearing partition wall.

Although it is possible to construct the vast majority of interior partition walls under insulated ceilings after ceiling gypsum board is installed, it was felt to be impractical as a long term strategy due to the increased complexity of trade scheduling. This approach requires additional trips for the framer, the electrician, the plumber, the gypsum board installers, and tapers. The development of an alternative strategy was felt necessary. Unfortunately, an appropriate strategy was not available until after the three Edmonton ADA houses were constructed. This alternative strategy, which eliminated trade scheduling difficulties is presented in SECTION V: SUBSEQUENT EVOLUTIONARY DEVELOPMENT OF THE AIRTIGHT DRYWALL APPROACH.

9. Split-Level Detail

The first ADA split-level house was constructed as part of the Edmonton project and necessitated the development of the construction detail presented in Figure 18, Pg. 36. Wood fire blocking, which was caulked to wall stud framing, was the key component in providing air barrier continuity between the one storey portion of the split-level and the second storey of the two storey portion of the split-level. Gaskets were installed on both sides of the fire blocking before gypsum board was installed.

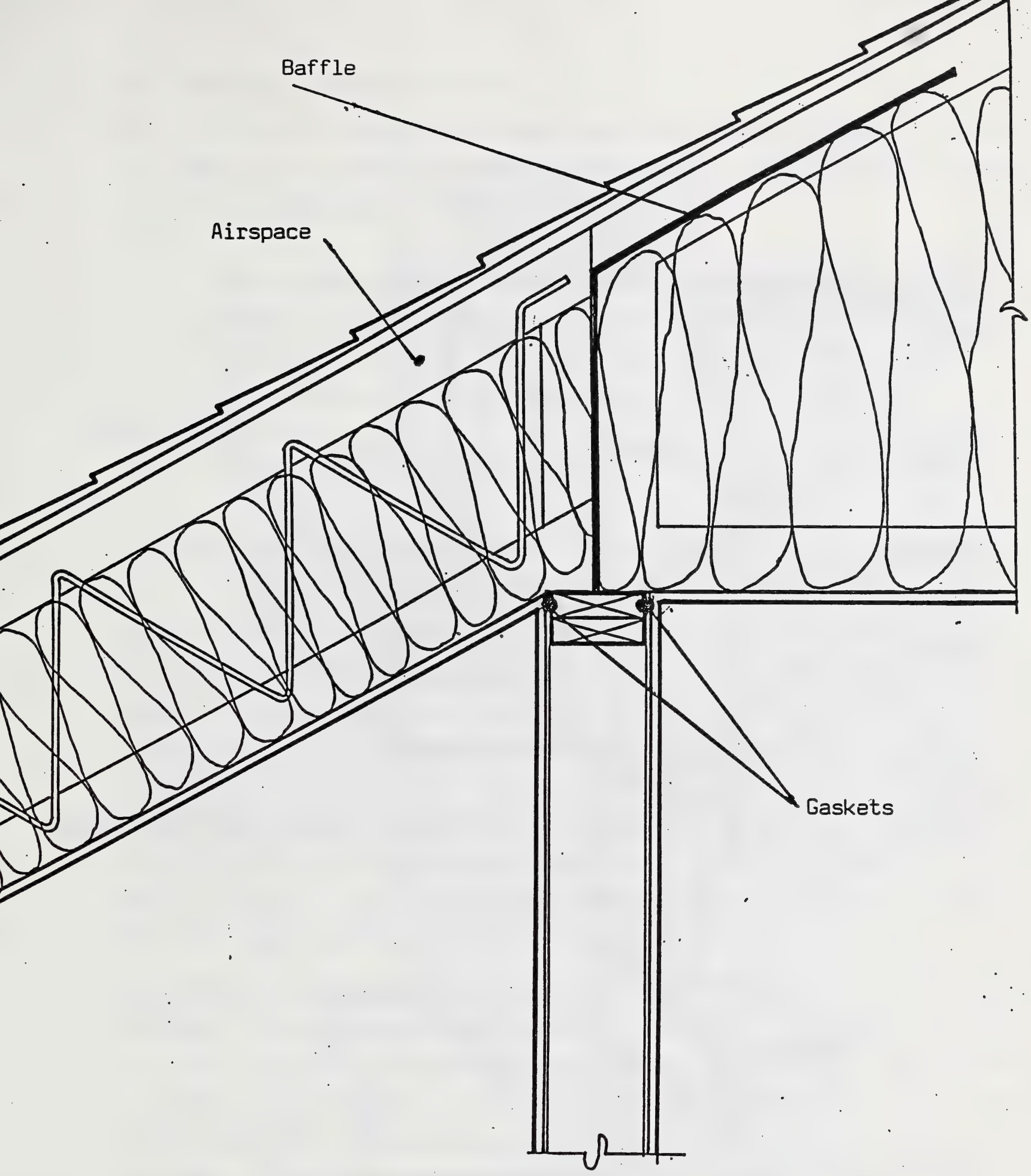


Figure 17: Load Bearing Wall - Sloped Ceiling

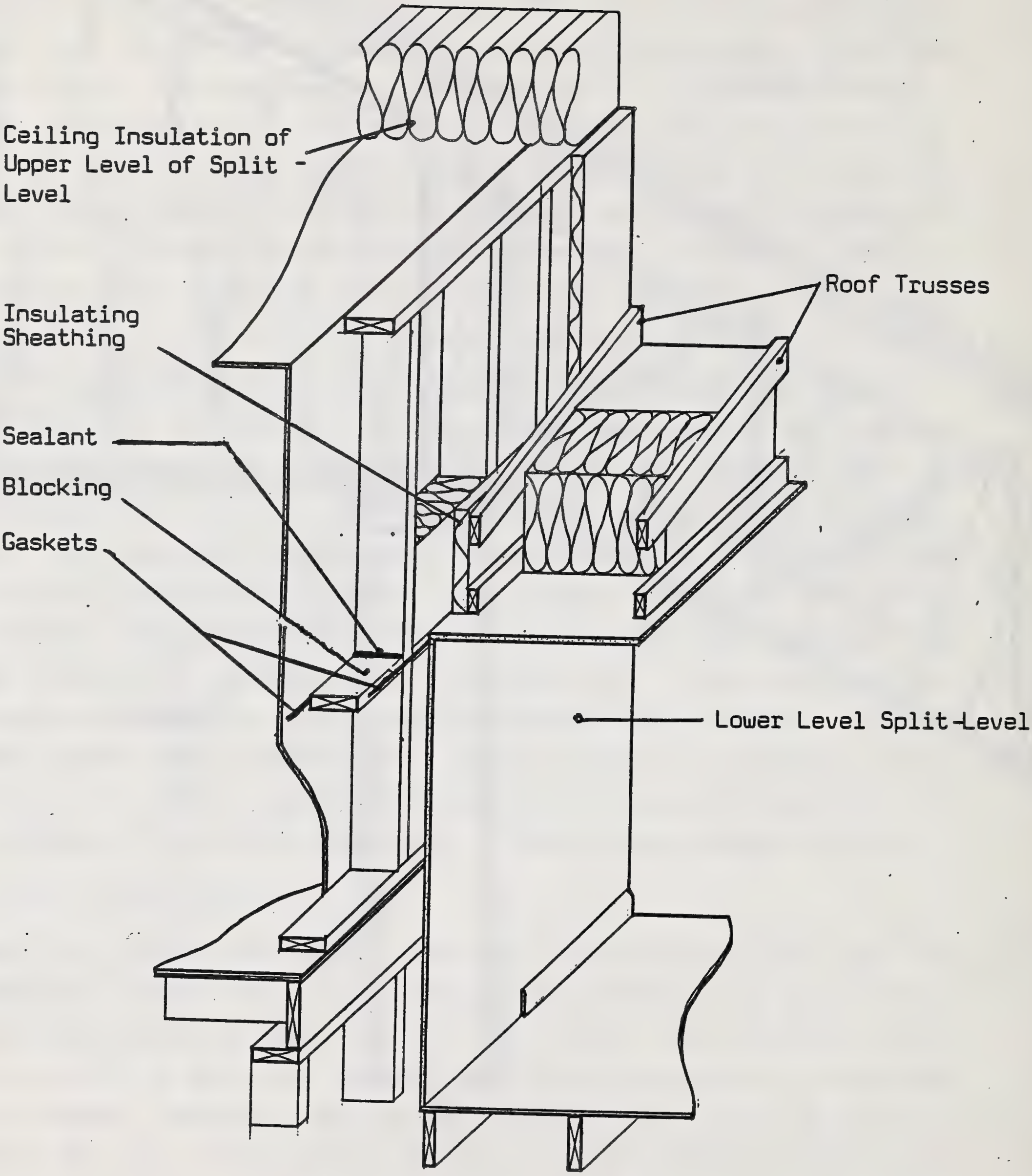


Figure 18: Split-Level Detail

10. Innovative Framing Details

Some innovative framing techniques were investigated with the intent of reducing the amount of framing materials in the buildings. The three major techniques investigated were:

1. The elimination of short pieces of framing material under window openings commonly referred to as cripples. These cripples can be shown to be redundant and their continued use only a hold over as a result of tradition.

2. The elimination of window lintels by relying on nail-on lintels.

3. Single top plate framing by lining up roof trusses directly over perimeter wall studs and floor trusses.

Of the three techniques, only the first two were incorporated into the three Edmonton ADA houses. The last technique was felt to have merit, however, it was felt that utilizing this technique in addition to introducing the ADA concept in one demonstration project would unduly complicate framing. All three techniques have been previously proposed in the OVE (Optimum Value Engineering) approaches promoted in the early 1970's by the National Association of Home Builders in the United States. It is unclear why these techniques have not become part of common framing practice in North America.

The first technique needs no further explanation as it is self evident. The second technique relies on the shear strength properties of nails to provide for adequate load bearing properties. The window lintels are typically a single piece of framing material and are either nailed on the surface of the wall framing, necessitating the notching of insulating sheathing around the lintels. Alternatively, the walls studs can be notched to accommodate a single framing member. Both approaches allow for faster framing and less material, yet provide adequate strength. Unfortunately, local building code requirements often require "professional" design if this technique is contemplated.

The third technique has been adequately documented elsewhere and will not be discussed here.

11. Space and Domestic Hot Water Heating

Space and domestic hot water heating requirements in all three Edmonton ADA houses were met by utilizing natural gas. However, all of the combustion appliances in the three houses were aerodynamically uncoupled in that their operation was not influenced by the interior house or exterior air pressures. The first two houses both utilized induced draft, medium efficiency forced air gas furnaces which vented through exterior perimeter walls instead of through typical chimneys. Induced draft, gas fired domestic hot water heaters were also used. The third house utilized only one source of combustion to provide both space heat and domestic hot water. This was accomplished by coupling an induced draft, gas fired domestic hot water heater to a fan-coil. A fan-coil is a water-to-air heat exchanger attached to a hot water tank. A water pump is used to circulate hot water through the heat exchanger and back to the domestic hot water tank. A fan or blower then moves house air as part of a forced air heating system over the heat exchanger, thus heating the house air.

12. Ventilation

Ventilation requirements in the first two Edmonton ADA houses were met by coupling a central exhaust system (Figure 19, Pg. 39) to a heat recovery device which acted on the ventilation air, namely an air-to-air heat exchanger or ATAHE (Figure 20, Pg. 40).

Ventilation requirements in the third Edmonton ADA house were met by coupling a central exhaust system to a series of multiple intake inlets and relying on the induced negative pressure in the house as a result of the operation of the central exhaust system to provide for air flow through the intake inlets (Figure 21, Pg. 41).

Recommended operating ventilation rates were determined by the application of ASHRAE Standard 62-1981 which has the following requirement for outdoor air:

- 5 litres per second (10 cfm) per habitable room.

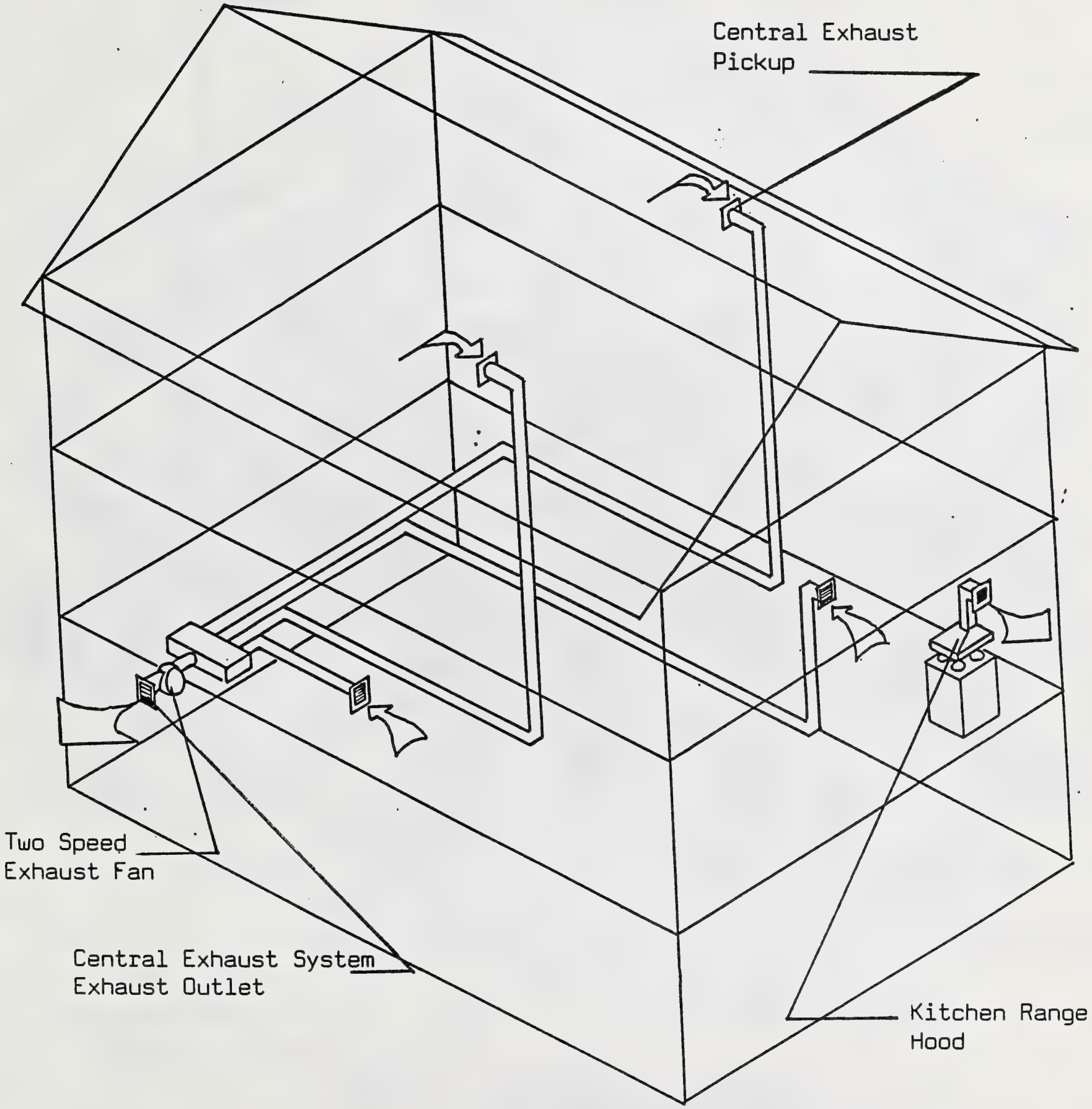


Figure 19 : Central Exhaust System

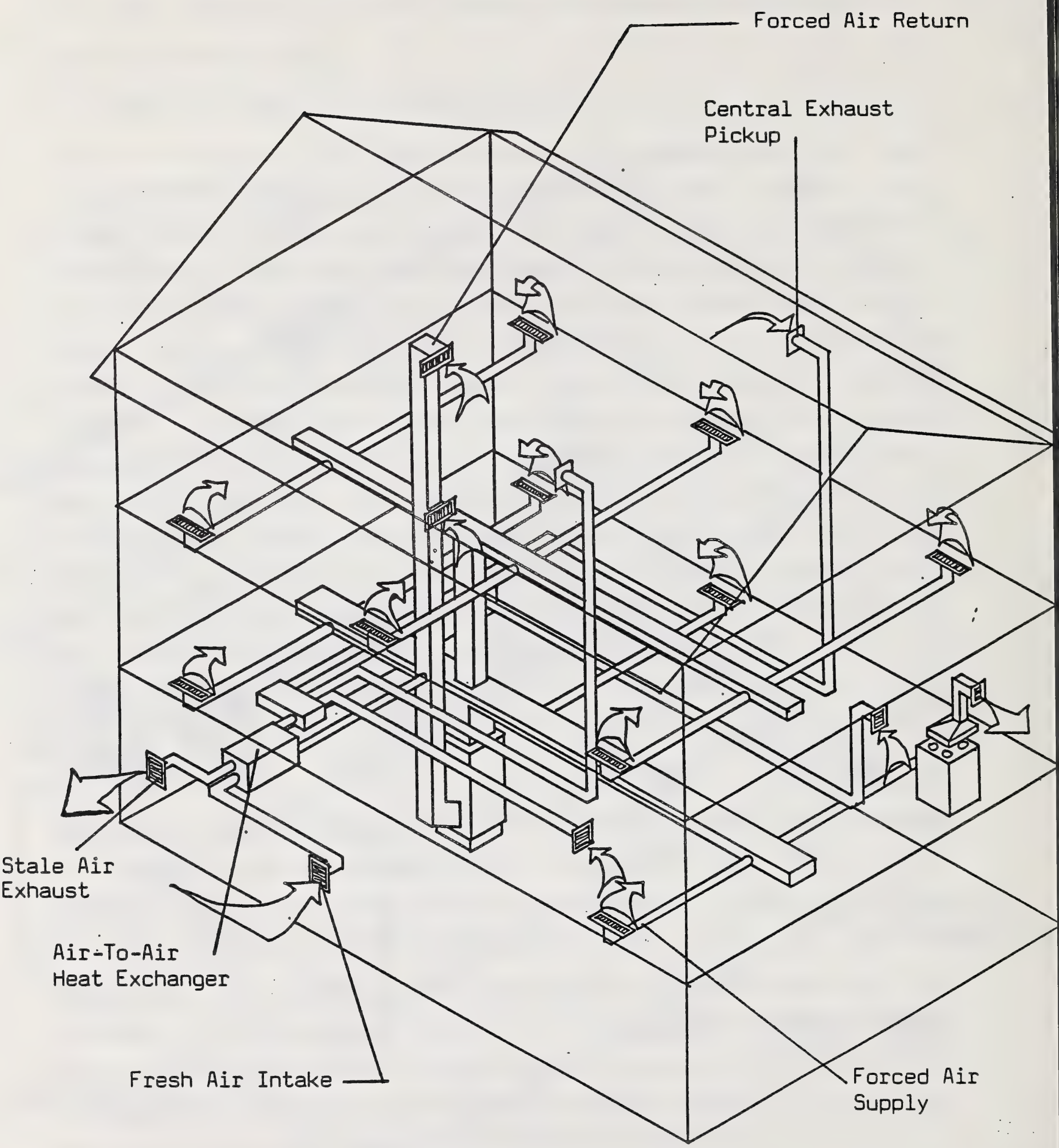


Figure 20 : Central Exhaust System
Single Intake Inlet
Heat Recovery On Ventilation - ATAHE
Forced Air Space Heating

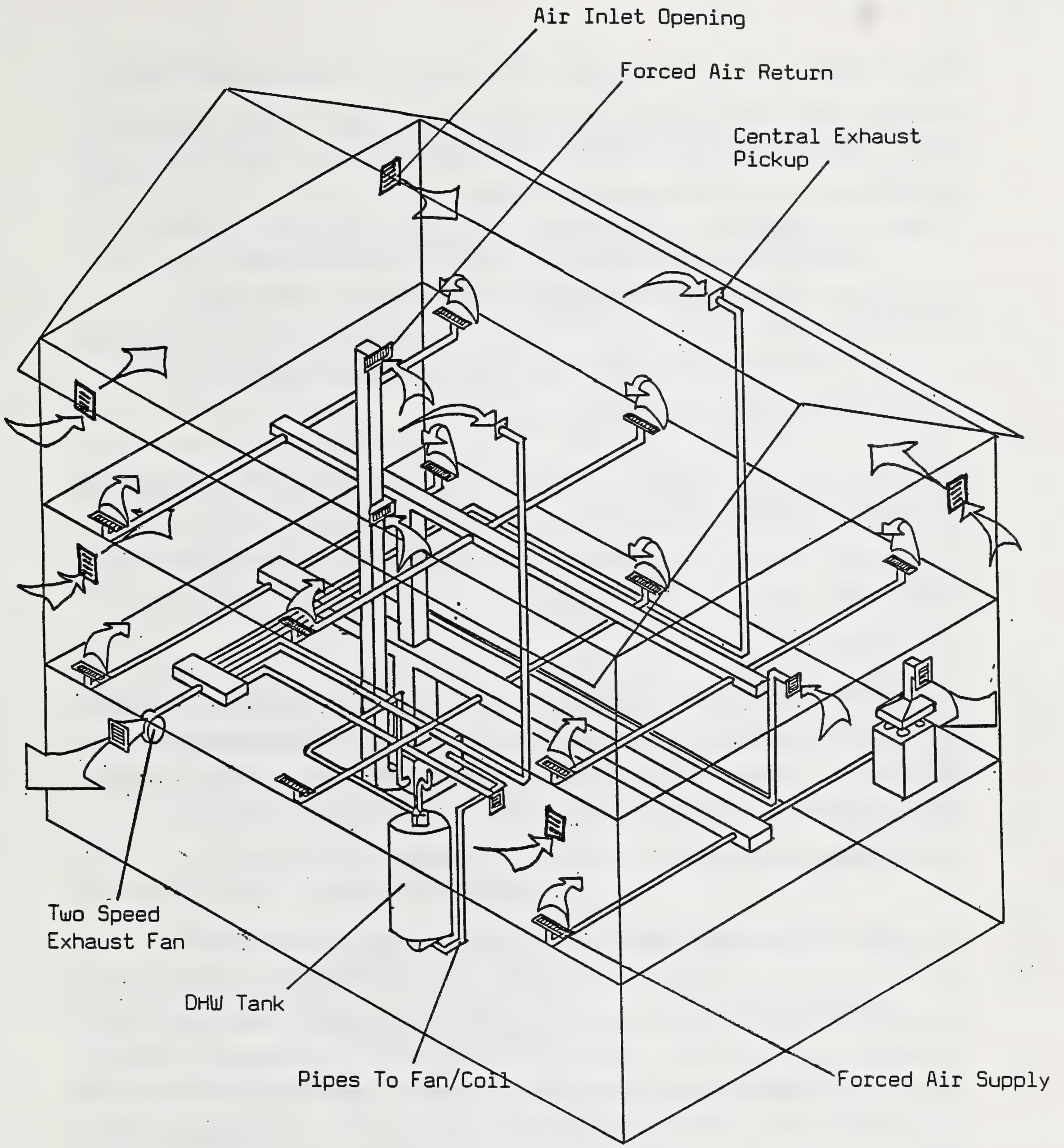


Figure 21 : Central Exhaust System
No Heat Recovery On Ventilation
Forced Air Space Heating-
Fan-Coil On DHW

This requirement is independant of house size, and includes bedrooms, living rooms, dining rooms, kitchens and any other rooms in the house. This standard also provides for additional air requirements for bathroooms and for kitchens as follows:

- 25 litres per second (50 cfm) for each bathroom supplied on an intermittent basis when a bathroom is used; and

- 50 litres per second (100 cfm) for kitchen exhausts on an intermittent basis when required.

It should be noted that the ASHRAE standard was used to determine recommended operating ventilation rates, but that the system was sized in a manner that it was capable of delivering 0.5 air changes per hour should that rate ever be required.

13. Airtightness Testing

The three Edmonton ADA houses were tested for airtightness utilizing the Canadian General Standards Board Standard, "Determination of the Equivalent Leakage Area of Buildings By The Fan Depressurization Method" CAN2-149.10-M84 and the following results were obtained:

Bearspaw Show Home	0.5 airchanges at 50 Pascals negative pressure
River Ridge Show Home	0.8 airchanges at 50 Pascals negative pressure
Meadows Show Home	1.1 airchanges at 50 Pascals negative pressure

The three Edmonton ADA houses all achieved significant degrees of airtightness and easily met the R-2000 standard for airtightness which is 1.5 airchanges per hour or less at 50 Pascals negative pressure.

14. Incremental Cost

The incremental costs for the three Edmonton ADA houses are listed below:

INCREMENTAL COSTS ABOVE STANDARD CONSTRUCTION IN EDMONTON, ALBERTA
FOR ADA HOUSES CONSTRUCTED AS DESCRIBED IN SECTION IV.

CATEGORY	BEARSPAW	RIVER RIDGE	MEADOWS
Basement Finishing and Below Slab Insulation	$1,587.00	$1,435.00	$ 426.00
Insulating Sheathing	438.00	539.00	1,327.00
Additional Wall Insulation	645.00	502.00	380.00
Medium Efficiency Induced Draft Furnace	420.00	420.00	420.00
Induced Draft Hot Water Heater	165.00*	585.00	585.00
Air-to-Air Heat Exchanger Installed	1,250.00	1,250.00	500.00
Electrical	103.00	103.00	104.00
Frame Labour	459.00	847.00	400.00
Caulking and Gaskets	209.00	394.00	200.00
Windows	324.00	318.00	300.00
TOTAL	$5,497.00	$7,077.00	$4,642.00

* Electric water heater installed

These incremental costs are based on invoiced figures from standard tract trades relating to standard Edmonton, Alberta tract construction practices. For example, it is not standard practice to internally insulate basements, full height, to R.S.I. 3.5 (R-20) and provide finished and painted basement perimeter walls, nor to provide under slab insulation.

No air-to-air heat exchanger was installed in the Meadows Show Home. The $500.00 incremental cost in that category relates to the materials and labour associated with installing a central exhaust system with multiple intake inlets. No medium efficiency induced draft furnace is costed in the Meadows Show Home. The incremental cost in that category relates to the installation of a fan-coil system and the back up electric heater to provide space heat.

D. Rationale and Plan For Long Term Monitoring and Testing

The monitoring program has two components: monitoring the change in airtightness characteristics of the three Edmonton ADA houses, if any, over time, and monitoring the areas of specific interest to low energy house designers, namely energy consumption and performance of specific energy related equipment.

The monitoring of energy consumption will continue until the end of the 1985/1986 heating season. It will be necessary to track airtightness characteristics over a five year period at minimum.

It has been postulated (Timusk; 1982) that the airtightness characteristics of buildings deteriorates over time due to the natural aging process of the materials comprising the building envelope and also varies seasonally due to seasonal changes in the moisture content of the framing materials. As well, there is an initial change in airtightness resulting from the drying of construction moisture.

The three Edmonton ADA houses have been tested to determine their airtightness characteristics at the completion of construction, prior to occupancy. Subsequent airtightness testing will be conducted seasonally in an attempt to track any changes in airtightness. Three standard construction houses have been selected to act as control houses and are also being tested in a similar manner to the three Edmonton ADA houses.

The three Edmonton ADA houses have been instrumented in order to track energy consumption and equipment performance. The areas monitored are:

- space heating energy consumption;
- efficiency of installed heat recovery equipment;
- local climatic conditions;
- interior temperatures;
- hot water energy consumption; and
- total electrical consumption.

The three control houses are also monitored in a similar manner.

Each house monitored has a number of temperature, humidity, and energy measuring sensors. In particular, there are interior temperature sensors at each storey to track interior temperature stratification. These sensors provide a dry bulb temperature indication. A dry bulb temperature for the exterior temperature of each house is also taken. House interior relative humidity is also sensed. Total electrical energy usage is measured. Gas consumption measurements for space heating and hot water heating are also measured.

E. Conclusions and Recomendations

1. Trade Interviews

Extensive interviews with the tradesmen who constructed the three Edmonton houses were conducted. Edited transcripts of these interviews are contained in APPENDIX E: TRADE INTERVIEWS FROM ALBERTA AIRTIGHT DRYWALL DEMONSTRATION PROJECT.

Examination of these interviews indicates significant dissatisfaction with the unusual scheduling which was necessary to maintain air barrier continuity across the tops of interior partitions where they intersected insulated ceilings. As was previously described, the gypsum board on exterior walls and insulated ceilings was installed first and taped. Interior partitions were then constructed and finished. This procedure resulted in additional trips to the job site for the carpenter, the electrician, the plumber, the gypsum board installer and gypsum board taper. These additional trips resulted in significant additional costs and scheduling complexity. Techniques are necessary which will allow the use of conventional scheduling practices.

The trade interviews also indicated dissatisfaction with the notching of the gypsum board sheets around the cast-in-place floor joists. Surprisingly, the notching of the gypsum board sheets themselves was not time consuming, adding only approximately two man-hours of time per 30 metres (100 ft.) of basement perimeter. The major difficulty lay with the caulking of the notched gypsum board to the floor joists.

The process was time consuming and labour intensive. An improvement in the detailing in this location is necessary.

The overall impression from the tradesmen regarding the Airtight Drywall Approach was positive, especially from those tradesmen who had previous experience with continuous, sealed, polyethylene wrapped houses. The gasketing technique proved to be popular with the frame carpenters who typically had an intense distaste for caulking in general, and caulking to polyethylene in particular.

2. Heating and Ventilating Systems

The interaction of the controlled ventilation system with aerodynamically uncoupled combustion appliances needs to be more closely examined especially from the perspective of installed costs. It is generally understood that aerodynamically uncoupled combustion appliances are necessary in sealed houses. However, the installed costs of such systems provide a significant disincentive to the construction of airtight houses with gas combustion appliances. Thus, a significant bias exists towards the use of electric space heating and electric domestic hot water heating in airtight houses. The incremental costs to utilize natural gas to provide space heat and domestic hot water in the three Edmonton ADA houses ranged from $600.00 to $1,000.00. Unfortunately, the use of electricity to provide space heat and domestic hot water is not cost effective in many regions of North America from an operation cost perspective.

Combined systems, which utilize one source of combustion to provide both space heat and domestic hot water, have the potential of reducing the overall cost of installing aerodynamically uncoupled combustion appliances in a house. The use of a fan-coil coupled to an induced-draft gas fired domestic hot water heater is one promising approach and was demonstrated in the Meadows Show Home. Unfortunately, many local building codes do not allow the use of a domestic hot water heater for space heating purposes. This was the case in Edmonton, and as such a supplementary space heating system was required, defeating the purpose of the combined system incorporating the fan-coil. This issue should be made a high priority with authorities having jurisdiction. Current regulations are typically based on high heat loss housing and old equipment characteristics. New equipment, specifically designed for such combined use, is now available for use in low energy houses.

3. Incremental Cost

Incremental costs for the three Edmonton ADA demonstration homes were sufficiently high to prevent the approach, as utilized in the Edmonton houses, from displacing current tract construction practices. However, as a result of subsequent improvements to the ADA techniques, specifically the elimination of basement gypsum board notching and trade scheduling difficulties, the ADA techniques have the potential to displace current continuous, sealed polyethylene air barrier techniques in tract construction situations. These two improvements are estimated to reduce the incremental costs previously presented by $1,500.00 to $2,000.00 per building. This cost reduction, coupled with a less expensive and more rational approach to utilizing combustion appliances in airtight houses is expected to make the ADA techniques cost competitive and marketable with respect to current tract construction practices (Note: these incremental costs are not comparable to non-production, non-tract builder incremental costs to achieve R-2000 standards. It is generally understood that tract builder costs cannot be compared to non-tract builder costs).

V. SUBSEQUENT EVOLUTIONARY DEVELOPMENT OF THE AIRTIGHT DRYWALL APPROACH

The three houses built in Edmonton, Alberta as part of the Alberta Airtight Demonstration Project, were completed in the summer and early fall of 1984. However, several difficulties with the approach remained, namely trade scheduling, notching of gypsum board sheets around cast-in-place floor joists, concerns regarding gasket durability, cost and long term performance. The latter two concerns became the major focus of a ten house ADA demonstration and research project in Winnipeg, Manitoba jointly funded by the Manitoba Department of Energy and Mines, and Energy, Mines and Resources Canada. The builder of the ten Winnipeg homes was Flair Homes, a major tract home builder in the Winnipeg region well known for their past experience with building double walled airtight polyethylene film homes. Construction of the ten Winnepeg houses began in September, 1984 and was completed by January, 1985. A detailed report on this project is expected in the near future.

The remaining concern with the ADA concept, trade scheduling, became the major focus of two American research and demonstration projects, a sixteen house demonstration project in the State of Oregon and a six house demonstration project in the State of Idaho. Both of these two projects were funded by the Bonneville Power Administration as part of their Residential Standards Demonstration Project. The Oregon houses were administered by the Oregon Department of Energy, and the Idaho houses were administered by the Idaho Department of Water Resources. Construction of the Oregon and Idaho houses commenced in August and September of 1984 and was completed by December, 1984 and January, 1985 respectively.

A. Flair Ten House ADA Demonstration Project

The ten houses constructed in Winnipeg subsequently became known as the "Flair Ten House ADA Demonstration Project". The question of gasket performance, durability and cost was resolved under this project only in the short term. Long term, in service gasket performance remains to be substantiated, however preliminary indications are excellent. Effects of building frame movement over time on gasket performance and overall airtightness is being studied as part of a long term, multi-year monitoring program. During the course of the monitoring program, air leakage tests will be conducted on a seasonal basis. Correlation of these air leakage test results to long term gasket performance and durability will be attempted.

Preliminary results from the Flair Ten House ADA Demonstration Project (Lstiburek; 1985), have indicated that the use of polyethylene foam rope, commonly refered to as sealant backer rod, is not a suitable gasket material. This is because polyethylene deteriorates over time, and the material has an extremely high compression set. In other words, the material, after being compressed under load for an extended period of time and subsequently unloaded, does not return to its original shape. It retains its compressed shape. In polyethylene foam rope this is due to the tiny air pockets within the material becoming ruptured when significant loads are applied. Ethafoam sill seal, another common gasket material also exhibits a high compression set for the same reason and therefore is also unsuitable for use as a gasket material in ADA houses. Favorable performance with respect to compression set has been obtained from closed cell neoprene and vinyl based glazing tapes and weather strips as well as gasket materials based on EPDM, a common gasket used in the automotive industry. Favorable long term durability is expected from these materials by virtue of their already established long service performance histories in the glazing, weather-stripping and automotive industries. The cost of these latter materials varies from \$0.16/metre to \$0.32/metre (\$0.05/ft. to \$0.10/ft.) depending on quantity ordered and availability. This results in costs of \$50.00 to \$150.00 for the gasket material necessary to complete a typical house.

Notching of the gypsum board sheets around the cast-in-place floor joists to achieve air barrier continuity was ultimately eliminated as a result of the experiences arising out of the construction of the ten ADA houses in Winnipeg. This was accomplished by virtue of sealing the continuous rim joist or header to the perimeter concrete foundation wall with a continuous bead of an appropriate sealant and by placing a gasket between the subfloor sheathing and the top of the rim joist and header (Figure 22, Pg. 51 and Figure 23, Pg. 52). Gaskets are also installed in a continuous fashion between the interior surface of perimeter concrete foundation wall and the top plate of interior perimeter basement wall framing and between the same top plate and the perimeter basement wall gypsum board. If the interior of the foundation wall is not finished or if exterior basement insulation is used, it is necessary to use a sealant to seal the basement floor slab to the perimenter foundation wall to provide for air barrier continuity.

B. Bonneville Power Administration ADA Demonstration Project

The proposed solution to the difficulties in trade scheduling in ADA houses arose out of the Alberta Airtight Drywall Approach Demonstration Project. However, it was not possible to demonstrate this proposed solution there. The proposed solution was subsequently demonstrated in the sixteen ADA houses built in Oregon and the six ADA houses built in Idaho during late 1984 and early 1985 under the Bonneville Power Administration ADA Demonstration Project. The solution involved constructing interior partition walls under insulated ceilings with a single top plate in place of a double top plate, allowing the ceiling gypsum board to be slipped over the top of already constructed interior partitions, much like gypsum board sheets on exterior perimeter walls are run behind intersecting interior partition walls. The single top plate allows room between the top of interior partitions and the underside of roof trusses to allow the drywall to provide a continuous air barrier on an exterior ceiling. Joints between gypsum board sheets are filled as per standard

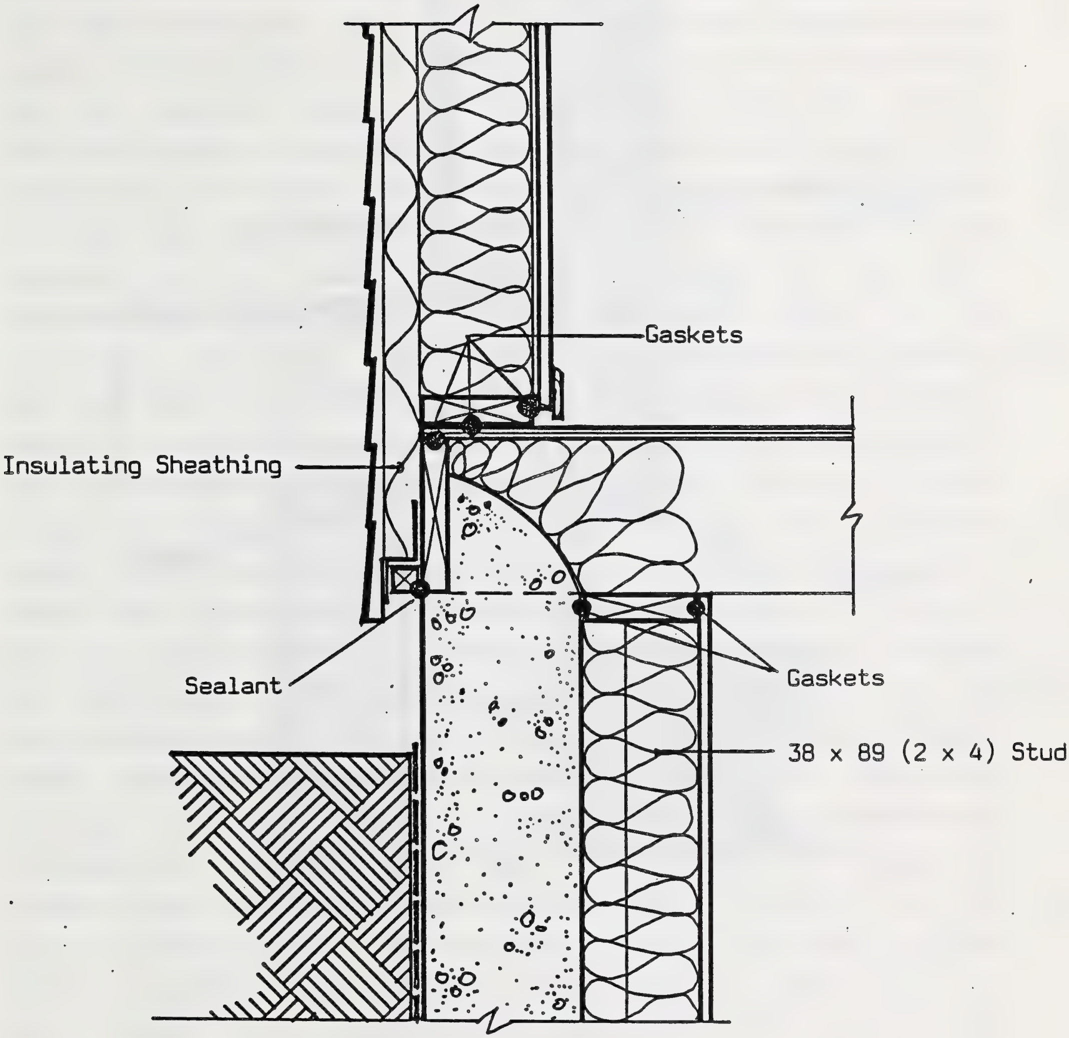


Figure 22: Subfloor at Grade - Western Detail

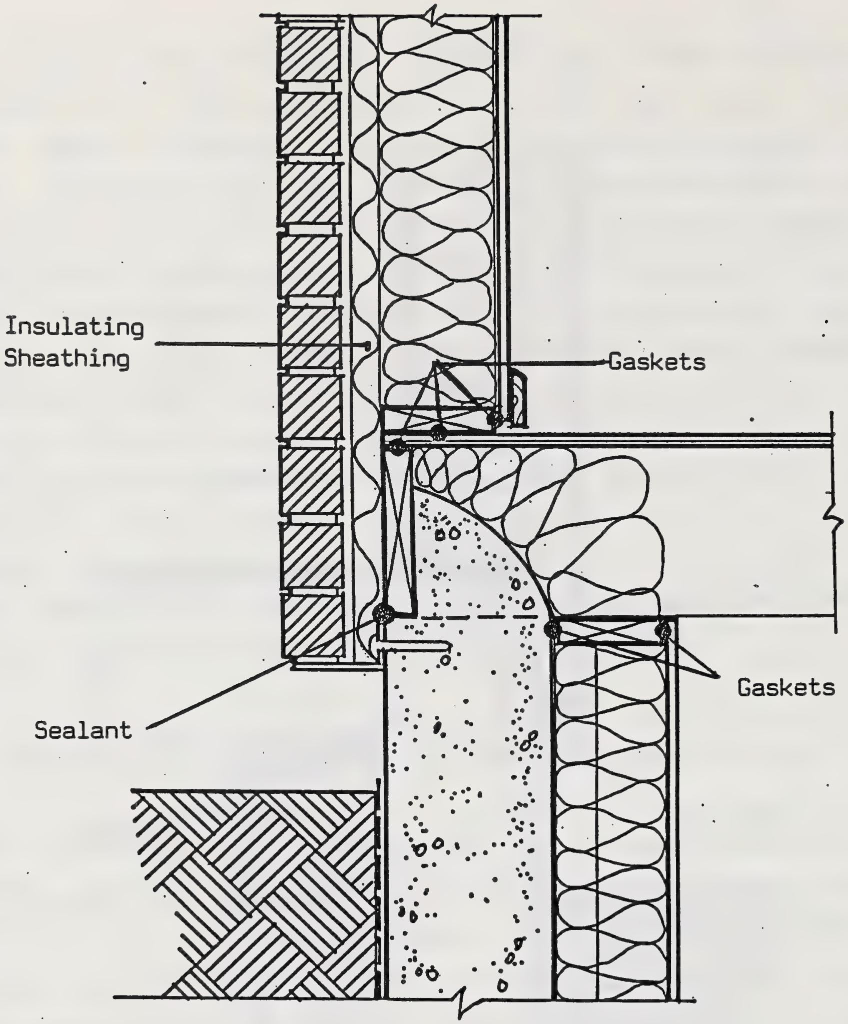


Figure 23: Subfloor at Grade - Western Detail, Brick Veneer

practice, after all the interior gypsum board sheets are installed. The short seams between gypsum board sheets, immediately above interior partition walls not able to be filled by the standard filling and taping operation, are filled by the gypsum board installers with quick setting joint filler immediately prior to the installation of the gypsum board on the interior partition walls. This modification in construction framing allows for all framing to be completed in one trip, all gypsum board installation to be completed in one trip, and all electrical, plumbing and mechanical to be completed as per standard trade scheduling (Figure 24, Pg. 55). Although the gypsum board or drywall installation occurs in one operation, the gypsum board or drywall is installed on exterior ceilings and exterior walls before the interior walls are boarded. Should it be necessary to constuct an interior load bearing wall under an exterior ceiling, then a continuous gasket is installed on both sides of a typical double top plate (Figure 25, Pg. 56). In other words, load bearing walls are constructed with double top plates, while non load bearing walls are constructed with single top plates. The non load bearing interior partition walls under exterior ceilings are not fastened to the underside of ceiling framing until after the ceiling gypsum board is in place. Significant labour saving in gypsum board installation now occurs as large sheets can now be effectively utilized on exterior ceilings. Interior partitions are subsequently fastened to the underside of roof framing by nailing through the gypsum board on the ceiling before gypsum board is installed on the interior partition walls. This nailing is typically done by the gypsum board installers. This requires nails which are at least 110 mm (4 1/2 ") long. This technique proved successful in all the Oregon and Idaho ADA houses. The only concern arising out of the use of this technique is the reliance of the builder on the gypsum board installers to insure that interior partition walls are perpendicular prior to fastening them to the underside of ceiling framing. This concern was shown not to cause difficulties during the course of the construction of the Oregon and Idaho ADA houses.

C. Canada Mortgage and Housing Corporation Non-Poly Experiment

Ten houses, built in Ottawa in late 1983 and early 1984, were chosen by the Canada Mortgage and Housing Corporation as part of a two year moisture research project. Of the ten houses, six houses are being intensively investigated. The moisture contents of preselected structural members in these six houses are being tracked. The final report and analysis of this project is expected in late spring of 1986. The discussiohich follows is preliminary and inconclusive.

Three of these homes are of standard construction with the exterior wall consisting of the following components:

- 12.5 mm (1/2") drywall or gypsum board
- 4 mil polyethylene
- 38 x 140 mm (2" x 6") wood studs at 400 mm o/c (16" o/c)
- fibreglass batts between the studs
- 12 mm (1/2") aspenite sheathing
- # 15 building paper
- vinyl siding

The remaining seven houses are constructed using the Airtight Drywall Approach with the exterior wall construction consisting of the following components:

- 12.5 mm (1/2") drywall or gypsum board
- 38 x 140 mm (2" x 6") wood studs at 400 mm o/c (16" o/c)
- fibreglass batts between the studs
- 25 mm (1") Glasclad insulating sheathing
- vinyl siding

The difference between the standard houses and the ADA houses was the exterior sheathing and the lack of polyethylene in the ADA houses. The Glasclad sheathing which was used on the ADA houses was installed such that the Tyvek surface faced inwards or to the warm side. In normal practice the Tyvek faces outwards or to the cold side. In

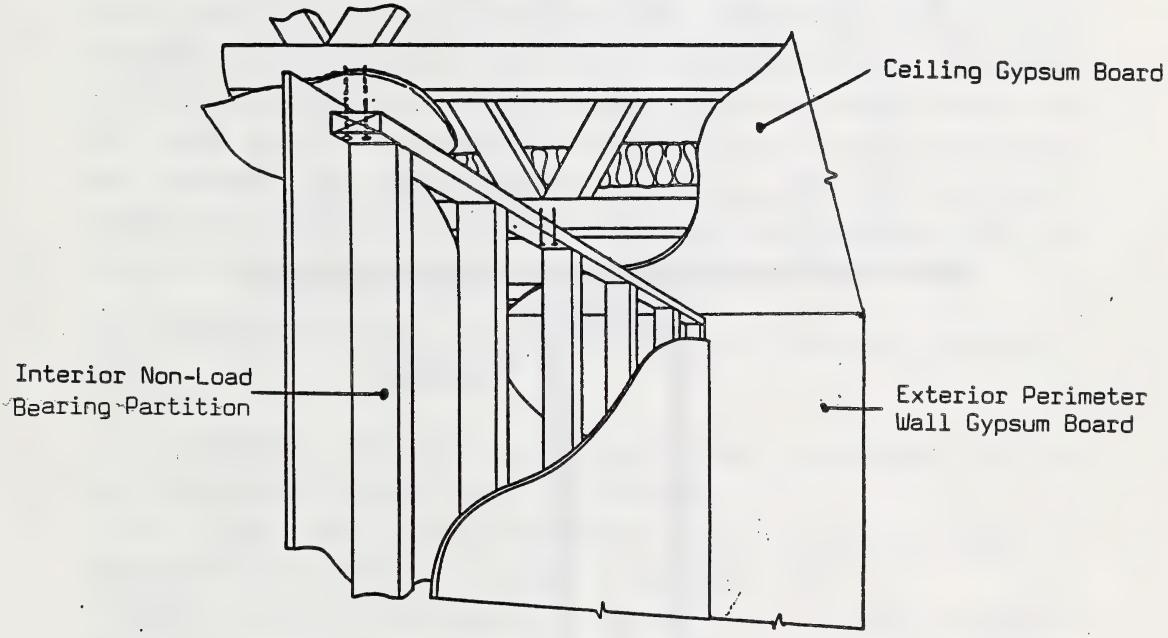

Ceiling Gypsum Board
Interior Non-Load Bearing Partition
Exterior Perimeter Wall Gypsum Board

Figure 24: Interior Wall Intersecting Insulated Ceiling

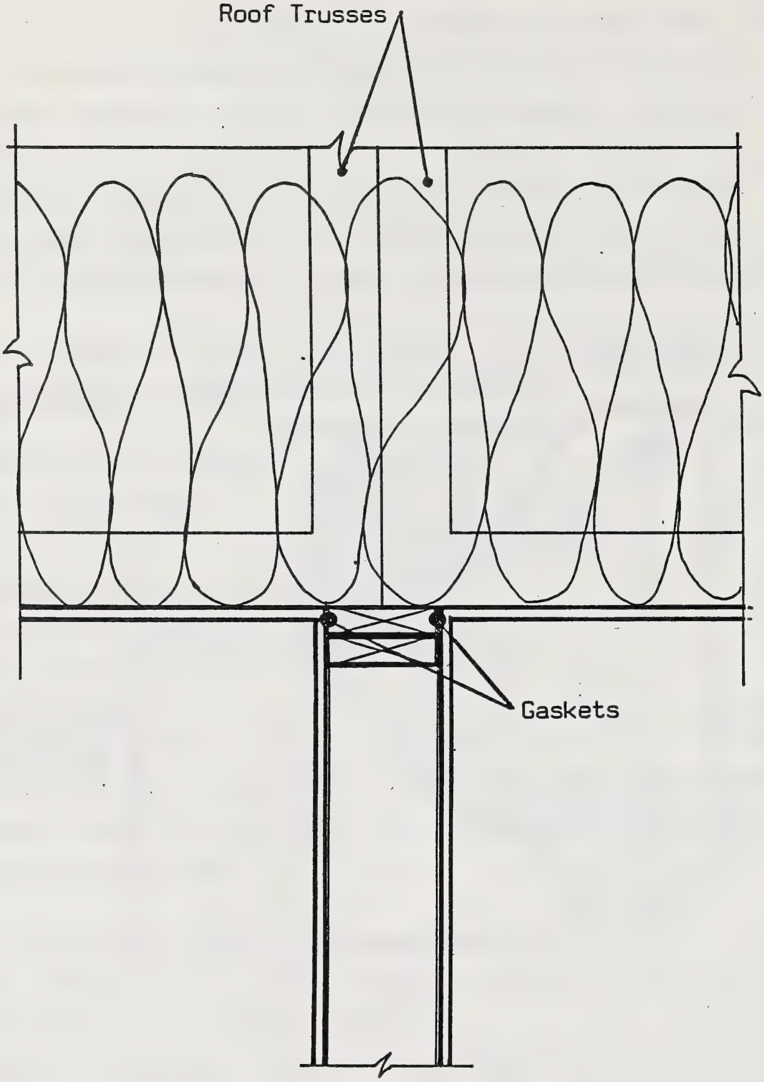


Figure 25: Load Bearing Wall Intersecting Insulated Ceiling

addition one of the ADA houses also contained a # 15 ashphalt-impregnated building paper between the Glasclad sheathing and the vinyl siding.

In each of the houses three studs of known moisture content were placed in one section of the exterior walls. Two of these studs were dry (less than 10 percent moisture content) and one of the studs was saturated (greater than 27 percent moisture content). Moisture pins were located in each one of these studs, near the warm face and near the cold face, at the top, in the middle and at the bottom. Moisture pins were also placed in the bottom plate and header or rim joist assembly. The moisture pins were then read manually once a week using an electronic moisture meter. By these means the moisture content of the studs at the top, middle, bottom and at the cold and warm faces was tracked. In the second week of October, 1984 the walls were opened and two of the studs in each house were removed and the moisture contents determined gravimetrically using ASTM methods.

The following preliminary observations resulted (Lischkoff, Lstiburek; 1985):

- No significant moisture content gradient was established in the studs through the length, width or thickness.
- All of the studs placed in the houses reached a moisture content of approximately 10 percent by the end of September, 1984.
- However, the wet studs placed in the ADA houses reached a moisture content level of 10 percent within 4 weeks. While the wet studs placed in the standard houses did not reach the 10 percent moisture content level for six months.
- About 50 percent of the aspenite sheathing was covered with black mildew when the wall cavities were opened in October in the standard houses.
- The Glasclad sheathing used in the drywall houses was found to be virtually dry in October and no sign of mildew was observed.
- In April when moisture was observed to be present in the Glasclad sheathing it was only present at the cold face of the sheathing, the

majority of the sheathing remained dry.

Although this project is still in its preliminary stages some of the following points may be relevant and be subsequently substantiated:

- The wet studs in the standard houses can only effectively dry to the exterior as a result of the polyethylene film. It is possible that wall drying occurs to both the inside and outside in the ADA houses.

- Many existing houses not containing polyethylene are not suffering moisture problems. This may be partially due to the interior cladding acting as an air barrier and vapour diffusion retarder and the ability of the interstitial cavities to dry, at least partially, in both directions.

- Under certain situations polyethylene films may enhance interstitial moisture problems by inhibiting drying.

VI. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations arise from the Alberta Airtight Drywall Approach Demonstration Project and the previous and subsequent research work related to that project documented in this report:

1. Providing high degrees of airtightness in new residential construction is within the project management and supervision skills of major tract homebuilders with the use of the Airtight Drywall Approach.

2. The overall reaction from the tradesmen and builders regarding the Airtight Drywall Approach was positive, especially from those tradesmen and builders who had previous experience with continuous, sealed, polyethylene air barrier/vapour retarder houses. The gasketing technique proved to be popular with the framers who typically had an intense distaste for caulking in general, and caulking to polyethylene in particular.

3. The incremental costs of providing high degrees of airtightness in new residential construction to major tract homebuilders are low when the Airtight Drywall Approach is used. However, the related costs of providing a controlled ventilation system and aerodynamically uncoupled combustion appliances necessary in airtight houses currently provides a significant financial disincentive to the construction of airtight houses, regardless of which technique has been employed to achieve airtightness.

4. The related costs of providing controlled ventilation systems and aerodynamically uncoupled combustion appliances have fallen significantly over the past two years and are likely to continue to fall as new products are introduced and competition increases. Significant business opportunites exist in this area for manufacturers and distributors. Builders concern is high in this area, yet many suppliers and product manufacturers appear disinterested or are

providing the wrong products at the wrong prices due to a lack of understanding of the builders' specific problems and/or a lack of understanding of the house as a system.

5. A significant bias exists towards the use of electric space heating and electric domestic hot water heating in airtight housing due to a lack of appropriate gas appliances and/or high capital costs associated with appropriate gas appliances.

6. Combined systems, which utilize a single source of combustion to provide both space heat and domestic hot water, have the potential of reducing the overall cost of installing aerodynamically uncoupled combustion appliances in houses. Unfortunately, many building codes do not allow for the use of such combined appliances and as such it is recommended that these building codes be examined in light of new information.

7. Concerns regarding a lack of moisture protection when using the Airtight Drywall Approach compared to the continuous polyethylene wrap do not appear to be valid in light of the research and current demonstrations. In fact, there may be legitimate concerns regarding the reduction of envelope drying due to the use of polyethylene. Building envelope durability may possibly be enhanced by not using sheet polyethylene in building construction in certain climates.

8. Long term durability of gasket and sealing materials used in the Airtight Drywall Approach remains to be evaluated conclusively. Current indications are positive, however, more study is recommended.

9. The effect of building frame movement, settlement and materials shrinkage on the long term airtightness of the Airtight Drywall Approach remains to be evaluated conclusively. Current experience suggests that differential movements between materials are taken-up by the gasket sealing approach and long term indications are positive, however, more study is recommended.

APPENDIX A

APPENDIX A: CONCERNS ABOUT THE USE OF POLYETHYLENE FILM IN RESIDENTIAL CONSTRUCTION

BACKGROUND

Polyethylene film was introduced into the residential construction industry in the early 1950's on a limited basis. It was initially used only to replace the asphalt-kraft paper vapour barriers which were used beneath loose fill attic insulations. These vapour barriers were originally designed to retard vapour movement by diffusion alone and not to stop the movement of air which may carry moisture with it. In essence the early use of the term vapour barrier actually referred to a vapour diffusion retarder.

Polyethylene was brought into wide use as a ground cover material in the crawl spaces of homes in the late 1950's and early 1960's. It was also promoted as a vapour barrier in the campaign to promote electric heating in houses in the 1960's, although in these houses it was also used primarily in the ceiling. The walls of these electrically heated houses were still insulated with insulation batts backed with asphalt-kraft paper which acted as the vapour barrier.

In the early 1970's polyethylene began to be widely used as an additional vapour barrier in the walls of houses and was installed over the traditional asphalt-kraft paper vapour barrier still found on insulation wall batts. Subsequently, in many cases it became one of the few code recognized vapour barriers in wall construction as the insulation manufacturing industry began to phase out the manufacture of asphalt-kraft paper backed batts.

In the mid 1970's it was recognized by the regulatory agencies involved in residential construction that air movement was a significant factor in moisture movement, although this information had been available from the research community since the early 1960's. Subsequently the use of the term air-vapour barrier was adopted. The air-vapour barrier was meant not only to retard vapour diffusion but also to prevent mass air movement. Polyethylene was thought to be able to serve this function of an air-vapour barrier and became predominantly promoted as such in the late 1970's. It was not however, installed in a continuous manner, nor were seams sealed. Joints were commonly only overlapped, and rim joists or header joists typically ignored.

The energy crisis of the mid 1970's served to focus attention on infiltration/exfiltration as a major source of energy loss and airtightness as a method of overcoming this energy loss. The design and construction of extremely low infiltration houses was encouraged and significant degrees of building envelope airtightness were in fact achieved in experimental and demonstration houses in the late 1970's and early 1980's. Building envelope airtightness in these latter houses was most commonly achieved through adapting installation practices of the typical polyethylene film air-vapour barrier and installing it in a sealed, integral fashion.

Today, building codes, government policy and regulatory agencies promote, encourage and in a few limited cases require sealed, integral polyethylene air-vapour barriers. However, the residential building industry is currently far from adopting this approach as standard practice. It is the author's opinion that it may be incapable of doing so regardless of the incentives or penalties offered due to the significantly increased levels of workmanship required to successfully utilize it. In addition, significant problems exist with sheet polyethylene from a materials standpoint as well as broader problems from a building science or systems perspective. These materials problems and building science and systems problems may lead to a significant reduction of the use of polyethylene film as the principal method of achieving an air-vapour barrier in the residential construction industry in the near future.

CHEMICAL COMPOSITION OF POLYETHYLEME

When small organic molecules, or compounds of carbon, are caused to be linked together to form long chains, or complex two and three dimensional networks, the process is called polymerization. This process is usually dependant upon temperature, pressure, and an appropriate catalyst. When the gas ethylene, $H2C=CH2$, is heated under pressure it polymerizes to form polyethylene. Ethylene is said to be the monomer of polyethlene. The polyethylene is usually in the form of a solid transparent mass consisting of $CH2$ units linked together in endless chains. The chains have as their backbone carbon atoms linked together with each carbon atom additionally linked to two hydrogen atoms.

The solidified polymeric mass may assume three types of geometric form: amorphous, crystalline, and oriented. The molecules in the amorphous state are arranged in a completely random manner, while if they exhibit a degree of regularity they may assume an ordered arrangement or a crystalline state. Polyethylene is a crystalline polymer but it typically has different parts of the same molecule in a number of ordered arrangements and other parts in amorphous regions. When a tensile stress is applied to a crystalline polymeric mass the molecular chains become aligned or oriented parallel to the direction of applied stress. Such materials are said to be oriented (Blaga; 1973).

Orientation causes a closer packing of molecular chains increasing the forces holding the chains together. For example, tensile strength can increase significantly by the unidirectional orientation of a polymer over that of an amorphous polymer. In oriented materials, hovever, material properties vary with molecular alignment. Hence, in sheet polyethylene, or polyethylene film, the material is stronger in the direction of orientation than the strength of the material at right angles to the direction of orientation. In the manufacture of polyethylene film these directions are referred to as machine direction and transverse direction respectively.

The polyethylene polymer is typically mixed with numerous additives to reduce deterioration during production and use as well as to facilitate processing. The end products physical, chemical or electrical properties are usually altered in this manner. This physical mixture of a polymer and an additive is called a compound.

Recent surveys (Rode; 1983) indicate that common additives to polyethylene include:

- pigments (carbon black)
- flame retarders (antimony trioxide, halogenated metals)
- slip agents/antiblocking agents (oleamide)
- blowing agents (pp'-oxy-bis-benzene sulphany hydrazide, azocarbonamide)
- plasticizers (polyisobutylene, butyl rubber)
- cross-linking agents (dicenyl peroxide)
- antioxidants (amines, phenols, DLTP)
- processing stabilizers (2-6-5-butyl-4-methyl phenol, Topanol CA, Nonox WSP)
- weathering agents (carbon black)
- antistatic additives (polyethylene glycol alkyl ester).

These common additives are typically grouped into classes. The three classes of additives of interest to this paper are: lubricants, stabilizers and plasticizers.

Lubricants provide external and internal lubrication in plastic compounds. Of specific importance to polyethylene film manufacture are additives which reduce friction between the polymer and metal surfaces of the dies and other processing equipment. Without the addition of lubricants, degradation can begin to occur during processing and as such impair long term durability.

Protection against polyethylene degradation caused by heat, oxidation, and solar radiation can be provided by the addition of stabilizers. The three groups of stabilizers used in polyethylene manufacture are: thermal (heat) stabilizers, antioxidants and ultraviolet light stabilizers (UV stabilizers).

Plasticizers are additives which improve processing and serve to reduce the brittleness of the end product. Material properties can change dramatically from hard, brittle, and glass-like to soft, flexible and tough (Blaga; 1973).

MATERIALS DEGRADATION PROBLEMS

Polyethylene films are susceptible to degradation due to chemical attack, radiation degradation, bacterial degradation, thermal degradation and thermal oxidation (Rode; 1984). These mechanisms will now be discussed as well as the influence of various manufacturing processes on these degradation mechanisms.

RADIATION DEGRADATION

The long-chained molecules comprising sheet polyethylene are attracted to each other by secondary forces (Ashton; 1969). In order to break these bonds energy is required. This energy can be supplied by radiation. One of the properties of radiation is that as the wavelength of radiation decreases, its energy increases. The energy required to break the carbon bonds in polyethylene occurs at a wavelength of 350 nm, a wavelength in the ultraviolet band. When polyethylene is exposed to ultraviolet light embrittlement of the polymer occurs. However, biologically active UV is only about one percent of the total radiant energy from the sun at the earth's surface due to the absorption of most of the solar emitted UV radiation by the earth's atmosphere. This atmospheric absorption allows organic materials some degree of exterior durability. The magnitude of the atmospheric absorption of UV radiation is dependant on both seasonal climate and location so that significant variation in the outdoor weathering of polyethylene occurs (Rode; 1984).

High energy irradition of polyethylene can initate the reverse of the polymerization reaction that resulted in the original production of the polyethylene. This process is sometimes referred to as the unzipping of the polymer (Ashton; 1969) and leads to catastrophic failure as it is a chain reaction. Additives which are classed as UV stabilizers are typically pigments which reflect the UV or absorb it preferentially to the polymer and convert it to heat energy. Carbon black is commonly used as an effective UV stabilizer due to its property of UV absorbtion. Other compounds, such as titanium dioxide and zinc oxide, are also effective UV stabilizers as a result of their ability to reflect UV rather than mearly absorb it.

The conversion of UV radiation to heat by the stabilizers can lead to elevated temperatures in the polyethylene leading to an increase in the rate of chemical reactions, such as oxidation, which may be occuring due to other reasons.

Concerns that the degradation of polyethylene film due to UV exposure, once started, could continue even after the UV source is removed, due to chain reaction properties of the process, have recently been expressed (Gridley; 1984) and serve to underscore the desirablity of access to the polyethylene for inspection purposes once installed.

High energy irradition also can result in the production of smaller molecules such as hydrogen gas forming as a result of chain scission. These smaller molecules react across the chains in a process called cross-linking. Continued cross-link formation interferes with crystallization eventually resulting in an amorphous polymer. As such the material becomes harder and brittle and the induced brittleness causes cracking.

If during the cross-linking process sufficient oxygen is present, oxidation may occur. This polymer degradation process is thought to offset the effects of cross-linking (Rode; 1984) but does not stop the degradation process in general as it now is a combined process.

The UV degradation process is thought to be partially responsible for a recently documented (Eyre; 1984) incident of catastrophic failure of polyethylene film in a low energy house in Saskatchewan. It is likely that the polyethylene film utilized was insufficiently stabilized from UV degradation although it is possible to obtain highly UV stabilized film such as polyethylene films having a high component of carbon black. Unfortunately the vast majority of polyethylene film in use in residential construction in North America is insufficiently stabilized against UV degradation to provide adequate service life if current methods for accelerated UV degradation testing and UV degradation protection (Howard, Gilroy; 1969) are applied.

THERMAL OXIDATION

Oxidative degradation effects most polymers, however, hydrocarbon polymers such as polyethylene are specially susceptible (Ashton; 1970). Polyethylene films utilized in residential construction are typically manufactured and installed in environments which allow continued contact with oxygen contained in a gaseous state in the atmosphere. When the effect of temperature is superimposed, the rate of reactions increase. Oxidation, a slow reaction at room temperature in polyethylene, increases dramatically at elevated temperatures (Ashton; 1969). According to recent research "during thermal oxidation, the hydrocarbon groups of the polyethylene react with oxygen to form a hydroperoxide which results in cleavage at high temperatures to form an alkoxy and hydroxyl radical that abstracts hydrogen from the polyethylene" (Rode, Kilp; 1984).

Rapid oxidation of polyethylene film can also occur in the presence of ozone. Ozone is an extremely reactive gas that is an unstable derivative of oxygen gas and is an oxygen molecule containing three atoms instead of two. Materials which oxidize, such as polyethylene, will react with ozone. Concerns have been expressed that where electronic air cleaners are used in residential construction, the production of ozone as a result of their use, could lead to significant deterioration of polyethylene films used as air-vapour barriers.

Processing, which occurs at elevated temperatures, typically leads to some form of oxidative degradation, however, slow aging still occurs at service temperature. Particularly significant to thermal oxidation occuring in polyethylene films is frequent processing and subsequent exposure to oxygen as can occur when reprocessed or reclaimed material is used (Platts, Benson; 1984).

Specific additives, antioxidants such as amines and phenols, can retard the oxidation process by preventing the formation of hydroperoxide by the reaction of a hydrocarbon with oxygen.

Unfortunately the use of polyethylene films in residential construction which are appropriately stabilized against oxidation is next to nonexistent. In fact appropriate material is typically not available nor even manufactured. Recent testing conducted for Energy, Mines and Resouces Canada (Rode, Kilp; 1984) revealed that only one of the polyethylene films manufactured in Canada for use in residential construction came close to meeting the standard developed by the Swedish National Authority for Testing and Inspection based on an accelerated test method to simulate lifetime residential service. Furthermore, the testing revealed that great disparities existed between the actual performance of films from various manufacturers within the sample. Although all the samples tested met the CGSB

Standard for polyethlene films in residential construction, CAN2-51.33-M80, performance measuring oxidation resistance of the samples varied two orders of magnitude within the sample, with even the best sample performing poorly. Three methods of monitoring thermal oxidative degradation were used:

- polyethylene film samples were aged at elevated temperatures (95 degrees Celcius) for 10 days and 30 days, with mechanical properties such as tensile strength and percent elongation in both the machine direction and transverse direction measured after aging.

- infrared (IR) spectra of the samples were measured as a function of heating time at 99.6 degrees Celcius under an air atmosphere.

- differential scanning calorimetry (DSC) of the samples was carried out by heating the samples from room temperature to 180 degrees Celcius under a nitrogen atmosphere and determining the intersection of trace lines.

The test methods utilized correlated well with one another and there is some optimism that the test methods reflect long term behaviour under actual service conditions. Unfortunately, although it is possible to manufacture polyethylene film which will resist thermal oxidation over the useful service life of a house, and although it seems possible to provide for a standard for the manufacture of polyethylene film which deals with resistance to thermal oxidation and to test for compliance, such films are not currently available or manufactured for the residential housing industry and no current standard dealing with the thermal oxidation of polyethylene film exists or is contemplated. With respect to the development of an appropriate standard, it seems that political ramifications are the major hurdle, in that if such a standard is implemented it would imply (perhaps correctly) that current polyethylene films are completely inadequate to resist thermal oxidation. That would fly in the face of current multi-million dollar government sponsored promotion campaigns for the use of polyethylene films as air-vapour barriers in low energy housing.

THERMAL DEGRADATION

Temperature also effects polyethylene in a physical manner. A temperature increase softens materials that do not contain much cross-linking between molecules. Rate of change of temperature is also important as organic materials typically can accommodate slow rates of strain more readily than fast rates of strain. Furthermore, "thermal shock can cause cracking or exudation of plasticizer from plastics" (Ashton; 1969). Migration of the plasticizer out of the polyethylene can cause embrittleness and subsequent catastrophic failure to occur when external loads are applied on the polyethylene film such as wind pressure effects. Migration of the plasticizer may be rapid enough in typically installed polyethylene film in residential applications that brittleness can occur, depending on the composition of the polyethylene, within five years (Bowerman; 1983).

DEGRADATION DUE TO BIOLOGICAL ATTACK

Synthetic polymers are susceptible to attack by micro-organisms even though in general such synthetic polymers are not normally sources of food. It is not so much the pure polymer which is attacked, but the additives such as plasticizers and stabilizers which become the compounds of nutritional value for the micro-organisms. In the production of low cost polyethylene film it is not uncommon to utilize plasticizers containing fatty acid components. In such cases the probability of attack increases directly in proportion to plasticizer content unless inert plasticizers are used (Ashton; 1970).

It is now felt that conditions present in wall cavities and beneath concrete slabs are conducive to the biological attack of polyethylene films (Rode; 1983). Wall cavities are susceptible due to their high humidities and temperature and concrete slabs due to their contact with the soil and the micro-organisms contained within the soil. In fact, recent evidence (Maloney; 1984) may indicate that polyethylene degradation beneath concrete slabs could be quite common.

CHEMICAL ATTACK

Polyethylene film has excellent resistance to chemical degradation by a wide range of chemical reagents, non-oxidizing acids, alkalis and aqueous solutions (Rode; 1983). It is unlikely that the polyethylene films installed in typical service locations in residential construction come in contact with the limited number of chemical reagents which deleteriously affect it. Problems and concerns existed with the compatibility of polyethylene films and the numerous sealants and caulking compounds that the films came in contact with in the attempts to provide sealed polyethylene air-vapour barriers. These concerns and problems have been overcome with intensive testing and investigation of materials compatibility in this area by governments and regulatory agencies promoting energy conservation through airtightening and manufacturers wishing to promote their products.

Concerns have been recently raised (Riley; 1983) about the potential degradation of polyethylene in contact with concrete. Specific concerns centered around the numerous chemicals which may be added in low concentrations to concrete to modify its properties. These chemicals are typically accelerators, water reducers, retarders, super-plasticizers, air-entraining agents, fungicides, and corrosion inhibitors. However, a study commissioned to investigate this area of concern found no direct evidence of deleterious chemical attack on polyethlene films (Rode; 1983).

One of the few concerns in this area remains the reaction of polyethylene films to certain wood preservatives. It is felt that copper napthanate could induce degradation (Platts, Benson; 1984).

INFLUENCE OF FILM MANUFACTURING PROCESSES ON MATERIALS DEGRADATION

To the chemical industry, the production of polyethylene vapour barrier film has always been a very low margin product, and as such it typically attracts sufficient quantities of reclaim resin to significantly impact service performance. The use of reclaim material is further encouraged by the polyethylene film industry being a process industry with first pass efficiencies on the order of 90 percent, allowing 10 percent to be available for recyling (Platts, Benson; 1984). This reprocessing of material, depending on the mix of the chemical soup, can significantly reduce the resistance of the polyethylene film to thermal oxidation, as components of the raw materials may be subjected to the elevated temperatures of processing several times.

The actual process equipment used in the manufacture of film seems to be one of the single greatest sources of polyethylene film failure according to a recently conducted field survey of Canadian houses by the Canada Mortgage and Housing Corporation (Platts, Benson; 1984). A large percentage of the degraded films found in the field, contained brittle bands. Degraded material and durable material would coexist on the same sheet inches apart. These bands were found to be parallel to the machine direction of the film. This occured as a result of the polymer emerging from the process equipment die in a hetrogeneous and not homogenous condition. It has been postulated (Platts, Benson; 1984) that certain die designs can "hang up clumps or streams of polymer which cook for extended periods and then create hetrogeneity at the die lips".

In the same study it was also speculated that homogeneous instability is introduced by certain extrusion processes recently adopted, as numerous older samples of polyethylene film performed in a more durable fashion than relatively young samples. It was felt that the recent trend to higher pressure and higher temperature dies promote early degradation.

It has become obvious that in addition to standards specifying additives and chemical composition of polyethylene films being necessary, standards relating to process equipment will also be necessary.

SUMMARY OF MATERIALS DEGRADATION PROBLEMS

Significant material durability problems exist with currently utilized polyethylene films in the residential construction industry. These problems include UV degradation, thermal oxidation, thermal degradation, chemical attack, biological attack and built-in manufacturing process pre-aging. It is possible, in spite of these numerous and seemingly insurmountable problems, to manufacture polyethylene film for use in residential construction which will stand the test of time. Unfortunately such materials are either not being utilized or not available nor is there likelihood in the near future for significant changes to this state of affairs. However, even if durable polyethylene film in the materials sense was readily available, it is the author's contention that it would make little difference to the typical performance of polyethylene air-vapour barriers currently installed as durable polyethylene film would still not be able to adequately meet the other building science or systems concerns relating to air barriers and buildability. These building science or systems concerns will now be discussed.

BUILDING SCIENCE SYSTEMS PROBLEMS

Government regulatory agencies, while promoting the use of a sealed, integral polyethylene film air-vapour barrier, and ignoring the substantial materials problems discussed earlier, are stymied in their attempts to achieve widespread adoption to the technique. This has been due to one significant overiding fact: the sealed, integral polyethylene film air-vapour barrier technique is far too labour intensive, and hence too expensive to be adopted readily by the building industry. In fact, it is the author's opinion that large tract builders would not likely successfully adopt the technique even if cost were no object due to the significant amounts of supervision and training required. Furthermore, the material is typically too fragile to withstand the tract construction process. The development of super-polys with multiple cross-laminated plys and reinforcements has been an outgrowth of this concern. However, this trend may lead to impractical extremes with costs multiplying by orders of magnitude.

The difference between air barriers and vapour diffusion retarders seems to be lost on the industry in general and the government and regulatory agencies in specific. Agreement by the various proponents can be found with the concept of airtightness. Unfortunately, it is felt by many that airtightness can be practically achieved with polyethylene films and that the use of films to achieve airtightness in fact obey basic building science principles. Even if practicality were removed as a consideration, the use of polyethylene films to achieve airtighness would not be acceptable as the technique does not meet the basic requirements of an air barrier system. It is ironic that outside of a few researchers in the building science community, the industry has not defined the principles and characteristics of air barriers or more specifically air barrier systems.

Any material or system of materials may be used as an air barrier if the following requirements are met:

- The material, or system, must be continuous.

- The material, or system, must be impermeable to air (allowing not more than .1 litres of air to pass through the system per second per square metre at 75 Pascals).

- The material, or system, must be able to withstand the air pressure loads which act on it. That is, in addition to the influence of mechanical systems and stack action, the local peak wind loads must be taken into account.

- The material, or system, must be adequately stiff or rigid to maintain pressure equalization behind exterior cladding in order to control rain penetration under fluctuating wind pressures.

- The material, or system, must be durable and easy to maintain over the service life of the building.

When examining the sealed, integral polyethylene film system under these five requirements we find significant problems. The first requirement of continuity can be met by the poly-film approach as well as the second, that of impermeability of the system or material to air. The last three requirements, however, cannot be met with the poly-film approach.

The polyethylene film as it is currently being installed in practice is unable to withstand the air pressure loads which act on it. To be effective, the polyethylene film must be supported to resist wind and stack air pressures. Recent work carried out at the Division of Building Research of the National Research Council of Canada by R.L. Quirouette indicates that simply suspending polyethylene between wall studs, caulking the seams and fastening battens over the joints is not sufficient to allow the polyethylene to resist wind and stack air pressures. Under peak wind loading, the polyethylene will be sucked into the wall cavity, rupture its seal and compress the insulation. In addition, under fluctuating wind load conditions, the polyethylene film will billow in and out causing a pumping action resulting in rain deposited water on the surface of the exterior cladding being sucked inward. The polyethylene film must therefore be rigid in addition to being able to withstand necessary wind loads. Techniques which provide the necessary support for the polyethylene are prohibitively expensive. It may be more practical to use other materials, such as the interior cladding, as the air barrier rather than the polyethylene film.

The last requirement of an air barrier, or air barrier system, is also not being met by the current polyethylene film system. The materials durability problems have been previously discussed. While materials durability problems can be overcome, however, the problems of system maintainability may not be practical to overcome. In current approaches, the polyethylene is hidden within the exterior walls of a building envelope. When flaws in the air barrier occur, repairs, or maintenance is not easy. In fact it is unlikely that problems will be noticed at all.

CONCLUSIONS

Significant materials problems and building science systems problems exist with the use of polyethylene film in residential construction. The basic materials problems can be resolved, however their resolution is not likely in the immediate future due to institutional inertia. The building science systems problems may possibly not be overcome in a practical and cost effective manner which will allow continued, widespread use of polyethylene film in residential construction as an air barrier system. It is likely that the use of polyethylene film in residential construction will be significantly reduced in the foreseeable future.

APPENDIX B

APPENDIX B: MOISTURE MOVEMENT AND CONTROL

INTRODUCTION

The goal of building envelope design and construction is to provide an affordable, buildable and durable structure. The enclosure must be affordable from the perspective of both the builder and the purchaser. The end product also must be practical to build. It should not overtax the ability of the builder from the perspective of project management, quality control and supervision. Finally, the building envelope should be durable, or at minimum be maintainable over the useful service life of the building. Useful service life is being defined here as twice the typical mortgage period, or 50 years.

Of all the requirements of building envelope design and construction outlined, namely affordability, buildability, durability and maintainability, the last two, durability and maintainablity are often sacrificed in order to provide for the first two. Typically, this is due to the belief that the first two requirements are mutually exclusive of the second two requirements. It is the author's belief that these requirements are not exclusive, but rather are fully compatible. What is lacking is an understanding of the factors affecting building durability.

Of all the factors affecting building durability, the most significant is moisture. Moisture induced deterioration is the single largest degradation mechanism operating on North American buildings with costs running into the billions of dollars yearly (Jennings; 1984). If moisture levels and moisture movement are controlled, then it is likely that a durable building will result.

In order to control moisture levels and moisture movement in buildings, the mechanisms governing such movement must be understood, along with the relative magnitude of each mechanism. Appreciating the magnitudes of each moisture transport mechanism are the key in developing an effective design and construction strategy to deal with moisture levels and moisture movement. When working with limited resources, it is unwise to concentrate a disproportionate share of those resources and effort on relatively minor factors, while allowing major factors to be ignored. Unfortunately, such has been the case over the past five decades, with respect to moisture movement in buildings. Ever since F.B.Rowely conducted his excellent pioneering work in Minnesota in the 1940's (Rowely; 1940), we in North America have been preoccupied by vapour diffusion. As we shall see below, of the four moisture transport mechanisms typically operating in building envelopes, vapour diffusion is a relatively minor one.

The four moisture transport mechanisms predominant in building envelopes are:

1) Bulk moisture, in solid or liquid form, moving as a result of gravity, air pressure and/or hydrostatic pressure;

2) moisture movement due to capillarity;

3) air transported moisture movement; and

4) vapour diffusion.

Each of these mechanisms can act independently of one another and must be dealt with during design and constuction. The first two, bulk moisture movement and capillarity are primarily responsible for moving moisture into the building envelope from the exterior. The latter two, air movement and vapour diffusion, can move moisture into the building envelope from both the exterior as well as from the interior of the building enclosure, depending on exterior and interior conditions. For example, when a building is in a cold climate and is being heated, air movement and vapour diffusion typically move moisture from within the building enclosure into the building envelope. When a building is in a warm climate and is being cooled, air movement and vapour diffusion typically move moisture from the exterior into the building envelope. This duality of moisture transport function possessed by air movement and vapour diffusion is often overlooked by designers and builders. It is not unusual to find cold climate building envelope designs employed in warm climate regions. Even more confusing to the builder and designer are conditions where both heating and cooling occur for extended periods of time. The region of North America where this occurs has been affectionately dubbed the rot belt and is testimony to the failure of builders and designers to recognize the duality of air movement and vapour diffusion processes.

BULK WATER MOVEMENT

The first moisture transport mechanism a designer and builder must deal with is bulk moisture, solid of liquid(usually water) moving under the influence of one or more driving forces, typically gravity, air pressure and/or hydrostatic pressure. This mechanism of bulk moisture movement is responsible for moving moisture from the exterior into the building envelope. It can be appreciated that a great deal of moisture in the bulk liquid state can get into a building envelope in the form of rain, especially wind driven rain. In addition, much moisture in the bulk liquid state can get into a building envelope as ground water moving under the influence of gravity and hydrostatic pressure.

This first moisture transport mechanism requires three components to operate:

1) bulk moisture in the solid or liquid form;
2) an opening or hole in the building envelope;
3) a driving force, be it in an air pressure difference, a hydrostatic pressure or gravity.

Understanding the role of these components gives the designer and builder flexibility in developing various strategies to control this first moisture transport mechanism.

A designer or builder can seldom control whether ground water is present or not and he certainly can not control rain, wind or gravity. However, a designer or builder can control the number of unwanted openings or holes and two of the driving forces, air pressure differences and hydrostatic pressure. The control of these two driving forces has been shown by experience to be the most effective and practical approach as it is typically next to impossible to build an enclosure without any holes or openings in it.

In the portions of the building envelope above grade, air pressure differences across exterior cladding can be controlled by the use of the rain screen principal (Garden; 1963). Below grade it has also been more effective to prevent or control the build-up of hydrostatic pressure than to rely on a barrier without any openings or flaws in it to resist the hydrostatic pressure.

CAPILLARITY

The second moisture transport mechanism a designer or builder must deal with is capillarity. Capillarity is the movement of moisture in porous materials under the influence of capillary action. This mechanism acts primarily to move moisture from the exterior into the building envelope. For example, blotter paper, with one end in contact with water, draws water into itself against the force of gravity as a result of capillary action. Capillarity is a function of pore size and available moisture. If pore size in a material is large, such as clear gravel and course sand, then capillarity will not exist. If pore size in a material is small, such as in concrete, silty clay (and blotter paper), then capillarity is possible.

Capillarity can be a major moisture transport mechanism in the portions of building envelopes where they are below grade or where they come in contact with the ground. Capillary draw, however, can also be a factor in building envelopes above grade such as where a film of water is deposited on the exterior of a building envelope as a result of rain action. This water film may be drawn into the building envelope under the action of capillary draw. This is illustrated by the water found trapped between the laps in horizontal wood siding. The water is held between the laps in spite of the influence of gravitational forces.

A designer or builder can control capillarity by controlling the pore size of the building material or building assembly selected. Materials can be selected which do not support capillarity as a result of their large pore size such as gravel, or materials may be selected which do not have any pores such as glass. Alternatively, capillary pores in susceptible materials can be filled to break the capillary draw such as is done when concrete basements are damp-proofed. Capillarity is also controlled by sealing connections between materials or by making the connections wide enough not to support capillarity. In the siding example, to control capillarity the seams at the laps could be sealed or alternatively the overlapping material spaced apart sufficiently so that water is not drawn up between the overlapping material as a result of capillarity. Joints between materials, above and below grade, must also be designed with capillarity in mind.

AIR MOVEMENT

The third moisture transport mechanism a designer or builder must deal with is air movement. The mechanism of air movement can act to move moisture from inside or outside the building enclosure into the building envelope. Air, depending on temperature, can hold varying amounts of moisture in the vapour state. When air moves as a result of an air pressure difference it will carry this moisture. If air containing moisture comes in contact with a surface below the dew point temperature, the air may deposit some of its moisture on that surface in the form of condensation.

For moisture to be moved as a result of air movement the three following conditions must be satisfied:

1) air containing moisture must be present;
2) an opening or hole must exist; and
3) an air pressure difference must exist.

An opening and moisture laden air are not sufficient. Moisture laden air will not be carried across an opening if an air pressure difference does not exist as well. In the same vein, moisture movement will not occur as a result of air movement if no moisture is present in the air or if there is no opening. Therefore, to control moisture movement as a result of the movement of air, three factors can be controlled, either individually or in combination, namely the moisture content in available air, the number, location and size of openings in the building envelope and the air pressure differential acting across the building envelope.

It is typically more practical to control the moisture content in available air and the pressure differential acting across the building envelope than it is to control openings in the building envelope. In heating climates, moisture content in interior air is often controled by utilizing air change to dilute interior moisture levels. In cooling climates with a high ambient vapour pressure, dehumidification is used to accomplish the same effect. Slight depressurization in heating climates can be used to induce infiltration across the building envelope to limit moisture problems. This recognizes the fact that cold infiltrating air does not carry much moisture along with it. In cooling climates, slight pressurization of a dehumidified enclosure, can also be used to accomplish the same result.

In other words, although controlling building envelope openings has been the recommended approach to dealing with air transported moisture, it is typically ineffective. This is because high degrees of airtightness are seldom achieved due to materials and workmanship problems. Furthermore, as building envelope airtightness increases, particularly in heating climates, the dilution of moisture in interior air by natural airchange decreases. This leads to increased moisture concentrations in interior air and subsequently to increased incidents of moisture induced envelope problems if the other two factors, (moisture content and pressure difference) are also not controlled.

VAPOUR DIFFUSION

The fourth, and final, moisture transport mechanism is vapour diffusion. It can act to move moisture into the building envelope from within the building enclosure as well as from the exterior. Vapour diffusion is the movement of moisture in the vapour state through a material. All materials are vapour permeable to some extent. Even sheet steel is permeable to vapour, although the process may take millions of years before an appreciable amount of water diffuses. The point is that materials are not able to completely stop vapour diffusion from occuring, they are only able to slow the process down, or retard it. Hence, the term vapour diffusion retarder is appropriate, not vapour barrier.

Vapour diffusion is thus a function of:

1) the vapour permeability of a material;
2) the driving force or vapour pressure differential;
3) the length of time the mechanism acts; and
4) the surface area involved.

In a typical building enclosure, the surface area and time can often not be influenced. Only the vapour permeability and the driving force can usually be influenced. The driving force or vapour pressure differential refers to the difference in amount of moisture or difference in moisture concentration across a material. If no vapour pressure difference exists across a material, then no moisture will move as a result of vapour diffusion.

In heating climates it is sometimes practical to reduce the driving force by reducing interior moisture levels, but this approach is limited by human comfort constraints. Hence, we are left to manipulate the vapour permeabilities of materials to control moisture movement by diffusion.

In a cold climate where a building is being heated, it is typical to have vapour diffusion act to move moisture from within the building enclosure into the building envelope. In a warm climate with high ambient vapour pressures where cooling is occuring, the opposite is often true. However, exceptions are common and often overlooked, such as a south facing, highly insulated wall with wood cladding which has absorbed moisture in the wood cladding during the evening due to high ambient relative humidities (note: wood absorbs moisture according to ambient relative humidity not vapour pressure). This moisture is driven out of the cladding during the day and into the wall by a high surface temperature caused by incident solar radiation. The vapour pressure gradient, under these circumstances, can act from the outside of the wall towards the interior of the building enclosure.

Since vapour diffusion is a function of surface area, if, for instance, 90 percent of a building envelope surface area is covered with a specific vapour diffusion retarder, then, all other things being equal, that vapour diffusion retarder is 90 percent effective. Continuity of a vapour diffusion retarder is not an over-riding factor where vapour diffusion is concerned. For instance, a paint film, of appropriate permeance, applied only on the interior exposed surface of a building envelope will typically act as an effective vapour diffusion retarder.

CONCLUSIONS

In addition to understanding the mechanisims governing the movement of moisture into and out of the building envelope, understanding the relative magnitudes of these mechanisms is also important. Of the four mechanisms, the first, bulk water movement is the most significant. This mechanism can move the largest amount of moisture most quickly into a building envelope. The building industry's historical preoccupation with rain and ground water attests to this fact.

The second moisture transport mechanism, capillarity, can also be significant, but it is an order of magnitude removed from bulk water movement. It has also been a historical preoccupation of the building industry.

It is the last two moisture transport mechanisms, air movement and vapour diffusion, whose significance and magnitude has been most misunderstood. Air movement, as a moisture transport mechanism, can be as significant as capillarity. Vapour diffusion, however, is typically an order of magnitude less in effect than both air movement and capillarity and is typically insignificant when considering the total moisture movement in a building envelope.

Building envelopes rarely fail as a result of moisture movement by vapour diffusion, however, they are commonly misdiagnosed as having done so. Dr. N.B. Hutcheon, formerly of the Division of Building Research, National Research Council of Canada, sums up the current state of affairs:

> "It was nearly 30 years from the time of F.B. Rowley's paper (on the use of vapour barriers to prevent condensation in insulated building constructions) before it was clearly established and widely accepted that the leakage of air from inside a building through constructions and not vapour diffusion alone was often the principal means by which water vapour moved to cold surfaces. The concept of vapour diffusion was not wrong but it was not the only way. It is incredible, in retrospect that it should have taken so long to reach this conclusion..."(Hutcheon; 1979).

It has been calculated that the movement of water vapour through a 2 cm (3/4") square hole as a result of a 10 Pascal air pressure differential is 100 times greater than the movement of water vapour as a result of vapour diffusion through a 1 square metre (10 sq.ft.) sheet of interior gypsum board (Rousseau; 1983).

In "Canadian Building Digest", No. 175, J.K.Latta states: "Air leakage is now considered the prime cause of most condensation problems in walls and roof spaces. If, therefore, a building can be made tight against air leakage it may not need a vapour barrier, as defined. On the other hand, if there are openings that permit air to leak from the warm side to the cold side of the insulation, adding a vapour barrier (even of zero permeance) that does not seal off openings will be useless."(Latta; 1976). Latta was on the right track; he also might have noted that controlling leakage area was not the only factor involved in moisture movement by air, that air pressure differences and actual moisture contents in air were also significant and typically can be manipulated more readily.

It should not be concluded that vapour diffusion should be ignored by builders and designers as a moisture transport mechanism. Rather it should not be the major or only moisture transport mechanism considered. In the past few decades it has been "the tail wagging the dog" with regret to moisture considerations in buildings.

APPENDIX C

APPENDIX C: VENTILATION AND HEATING SYSTEMS

Ventilation is the process of removing and supplying air by natural (exfiltration, infiltration, combustion) or mechanical (intake, exhaust) means to and from any indoor space. Controlled ventilation is defined here as mechanically supplying fresh outside air and exhausting inside air to maintain adequate indoor air quality (air change) and mechanically supplying air for combustion devices and air extraction systems (air supply).

In typical building envelopes, the normally random distribution of leakage openings influences the exfiltration/infiltration process which is responsible for the rate of natural ventilation. This random or accidental distribution of leakage openings resulting in accidental leakage does not provide assurance that adequate air change for health, safety and moisture dilution can take place. In fact, in some climates natural air change may be a factor in introducing excessive moisture into a building enclosure.

The random distribution of leakage openings in a typical house causes the instantaneous infiltration/exfilatration rate in the house to vary substantially due to the influences of wind pressures, stack pressures and pressures induced by air consuming devices. Thus, a house or areas of a house can have adequate natural air change at one point in time and not have adequate natural air change at a subsequent point in time. The variation can be so substantial that the infiltration/exfiltration rate may be on the order of 300 litres/second (8 times the usual continuous requirement) during a wind gust and moments later zero if the wind suddenly dies down and all the randomly distributed leakage openings accidentally and temporarily happen to fall along the neutral pressure plane.

At the neutral pressure plane, no pressure differential exists across the building envelope. Since air movement occurs only when pressure differences exist, no air movement occurs through a leakage opening located at the neutral pressure plane. As the neutral pressure plane moves as a result of the effects of wind and mechanical devices, infiltrating openings become exfiltrating openings and vice versa. Magnitudes of the pressure differences are also influenced by temperature differentials. These interrelated effects influence the amount of natural air change occuring at any particular point in time as well as the location of this natural air change.

As a result of the great variation in the rate of natural ventilation, it makes practical sense to assume that all houses are airtight and that all of the necessary exchange of air for air quality reasons will be accomplished by a continuously operating mechanical ventilation system. Furthermore, it should be assumed that it is necessary to distribute the fresh air within the house envelope to avoid dead areas in the house. Dumping all the fresh air into one region of a house will do very little for the air quality in other regions of the house.

With the foregoing assumptions, the designer or builder now only has to choose a ventilation rate. Unfortunately great disagreement currently exists as to an appropriate ventilation rate. The designer or builder should seek guidance from authorities having jurisdiction. Where building codes do not provide specific ventilation rates, the builder or designer may be left to rely on his or her best judgement. The author prefers to rely on ASHRAE Standard 62-1981 which has the following requirement for outdoor air:

- 5 litres per second (10 cfm) per habitable room.

This requirement is independant of house size, and includes bedrooms, living rooms, dining rooms, kitchens, bathrooms and any other rooms in the house. The standard also provides for additional air requirements for bathrooms and for kitchens as follows:

- 25 litres per second (50 cfm) for each bathroom supplied on an intermittent basis when a bathroom is used; and
- 50 litres per second (100 cfm) for kitchen exhausts on an intermittent basis when required.

It is permitted to ventilate habitable rooms within the enclosure through the kitchen and bathroom areas. In other words, it is possible to provide an exhaust pick-up in a bathroom and ventilate one or two bedrooms through the bathroom as a result of the negative pressure induced in the bathroom by the exhaust pick-up.

With the assumption of an airtight house and mechanical ventilation along with the selection of an appropriate ventilation rate, the entire question of air quality can be effectively dealt with. Numerous practical field solutions are possible. Several will be presented.

Before proceeding there is still the question of adequate make-up and/or combustion air, which must be dealt with.

The entire combustion air/make-up air issue can be dealt with by the application of a single principle: aerodynamically uncouple all combustion equipment from the influence of house interior air pressures. The only acceptable method of accomplishing this now is to install equipment that is not sensitive to interior air pressure variations. Such equipment includes induced draft gas hot water heaters, medium efficiency induced draft gas furnaces, condensing gas furnaces, sealed combustion equipment, balance flue devices, and pulse combustion equipment. While induced draft devices require combustion air from within the house, they have power fans to mechanically exhaust the products of combustion. That is, such devices mechanically induce a draft to occur and as such do not require draft control air to operate nor do they have a tendancy to backdraft from negative pressures that may occur within the house enclosure, since they are not influenced by interior house pressures. Most such appliances can withstand negative pressures in excess of 50 Pascals.

Fireplaces can be effectively uncoupled from the house enclosure by providing a combustion and draft control air duct running from outside the house to the firebox and by installing glass doors.

The application of the uncoupling principle effectively deals with the question of combustion/draft control air. Numerous specific field solutions are possible. Several solutions are outlined below.

Solution One

Install an induced draft forced air gas furnace with a duct leading from the outside directly into the return air supply to the furnace. In addition install an induced draft gas hot water heater and a central exhaust system venting all bathrooms. Install a standard kitchen exhaust system. (see Figures C-1 and C-5).

In this approach the central exhaust system runs continuously and the furnace fan is also set to run continuously. In this manner air quality and ventilation requirements are met as the furnace fan is constantly drawing in fresh air from the exterior and distributing it throughout the house and the central exhaust system is continuously exhausting stale air. The central exhaust system would be powered by a two speed fan with the high speed mode activated by timed switches in bathrooms when they are in use and by a centrally located dehumidistat.

The incremental costs of this solution would be:

induced draft furnace over std. gas furnace........	+$350.00
induced draft water htr. over std.................	+ 500.00
central exhaust system............................	+ 200.00
savings on bathroom fans..........................	- 100.00
TOTAL	$950.00

Solution Two

It is the same as solution one except the central exhaust system and fresh air intake pipe to the return side of the furnace duct system is replaced with a continuously operating air-to-air heat exchanger (see Figure C-10).

The incremental costs of this solution would be:

induced draft furnace over std. gas furnace	+$	350.00
induced draft water htr. over std	+	500.00
installation of air-to-air heat exchanger	+	1,000.00
savings on bathroom fans	-	100.00
TOTAL		$1,750.00

Solution Three

Install an electric forced air furnace with a fresh air intake to the return air side of the furnace and install an electric hot water heater. In addition install a central exhaust system as in solution one.

The incremental costs of this solution would be:

central exhaust system	+$	200.00
savings on bathroom fans	-	100.00
TOTAL		$ 100.00

Solution Four

Same as solution three except replace the central exhaust system and the fresh air intake to the return air side of the furnace and install an air-to-air heat exchanger.

The incremental costs of this solution would be:

installation of air-to-air heat exchanger........	+	$1,000.00
savings on bathroom fans.........................	-	100.00
TOTAL	$	900.00

Solution Five

Modify solution one or solution three by replacing the fresh air intake pipe connected to the return side of the furnace duct system with individual fresh air inlet openings located in each room of the house except bathrooms and kitchen. These openings would be located on exterior walls, possibly near the ceiling level to minimize drafts. The openings would be small and occupant controllable, allowing only 5 L/s flow at a design pressure difference of 7 Pascals (see Figures C-2 and C-3). The system would work as follows:

1) As air is exhausted out of the house enclosure by the central exhaust system, the neutral pressure plane is raised above the ceiling level, and the entire house is depressurized relative to the exterior conditions.

2) Due to the pressure difference across the building envelope (negative pressure on the interior, positive pressure on the exterior) fresh air is drawn into the house through the individual fresh air inlet openings located in each room.

The advantage of solution five is that each individual opening could be controlled by the occupant. Also potentially cold, incoming fresh air in this approach does not induce stress effects on heat exchange surfaces in forced air furnaces that can lead to corrosion and premature failure as is possible in the ducted intake approach in solutions one and three.

The disadvantage of solution five is that the openings must be sized so as to allow only 5 L/s, to prevent uncomfortable drafts, and that the system is practical only in tight houses. In leaky houses, far too much air would have to be exhausted to achieve the depressurized condition, raising the neutral pressure plane above ceiling level, so as to induce infiltration forces across the entire building envelope. However, in tight houses exhausting only the volume of air as calculated by ASHRAE 62-1981 for air quality reasons will serve to move the neutral pressure plane above the ceiling level.

Solution Six

Same as solution five with the addition of a heat pump heat recovery system. Since, in this solution, air infiltrates everywhere across the building envelope except where the central exhaust system is exhausting interior air, it is possible to employ heat recovery at the central exhaust system exhaust outlet (see Figure C-7). Warm, heated air is leaving the building enclosure at only this one location. A heat pump is used to recover the heat in the air which is being exhausted by the central exhaust system, and this heat is commonly dumped into the domestic hot water system.

By employing this heat recovery strategy, it is not necessary to build a completely tight house for energy efficiency. Any randomly occuring leaks in the building envelope will always have air infiltrating across them. The heat which which is expended in warming this infiltrating air is recovered at the central exhaust system outlet by the heat pump. As such, it is possible with this approach to build a leaky house (as compared to the extremely tight houses of the R-2000 program) and yet still meet the energy performance of the best low energy airtight houses.

The heat pump heat recovery device for ventilation can also be used to provide for heating the domestic hot water supply year round, thus, halving the typical time period for capital cost amortization. The system is also fully compatible with electric baseboard heating as minimal duct work is required.

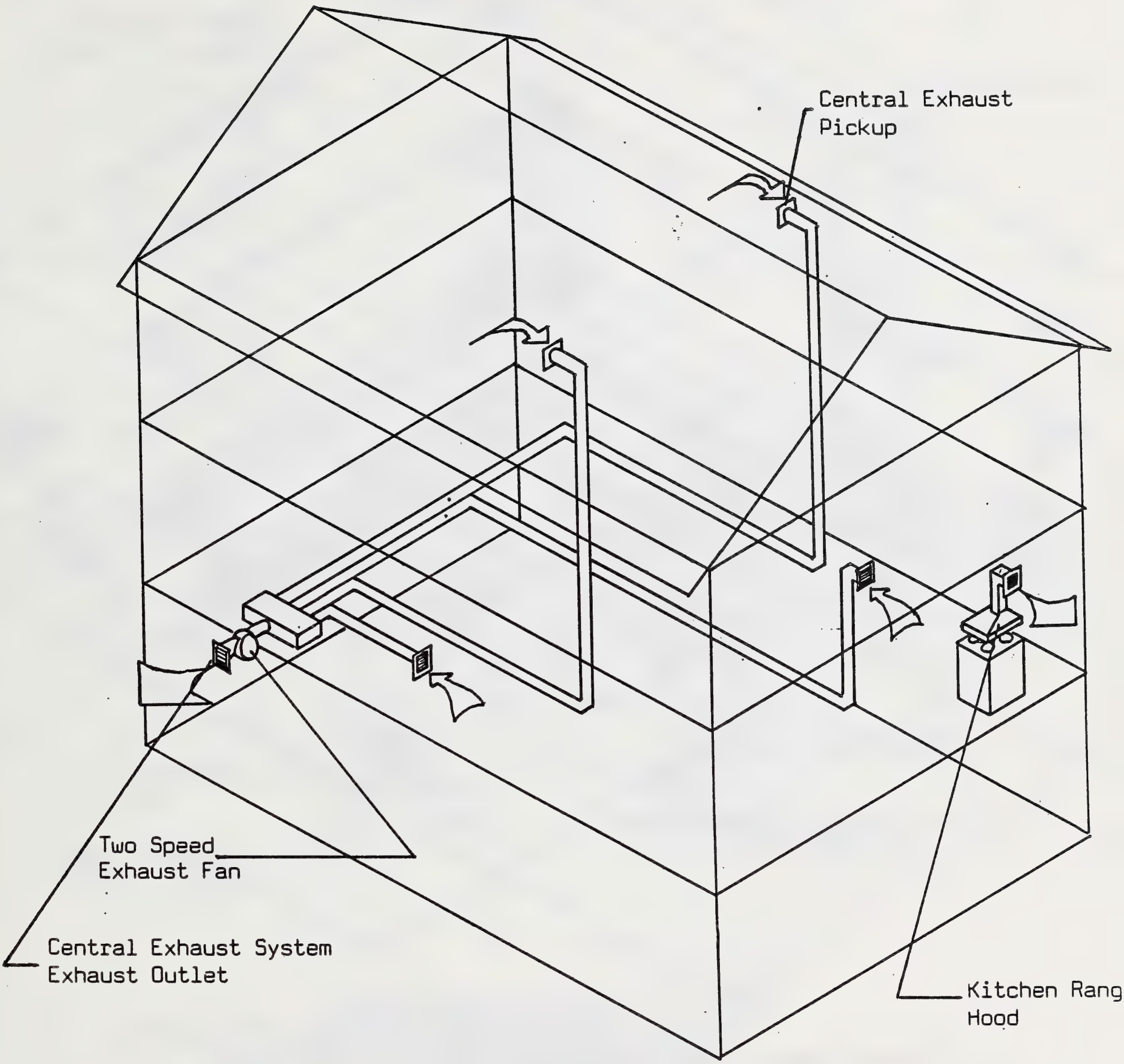


Figure C-1 : Central Exhaust System

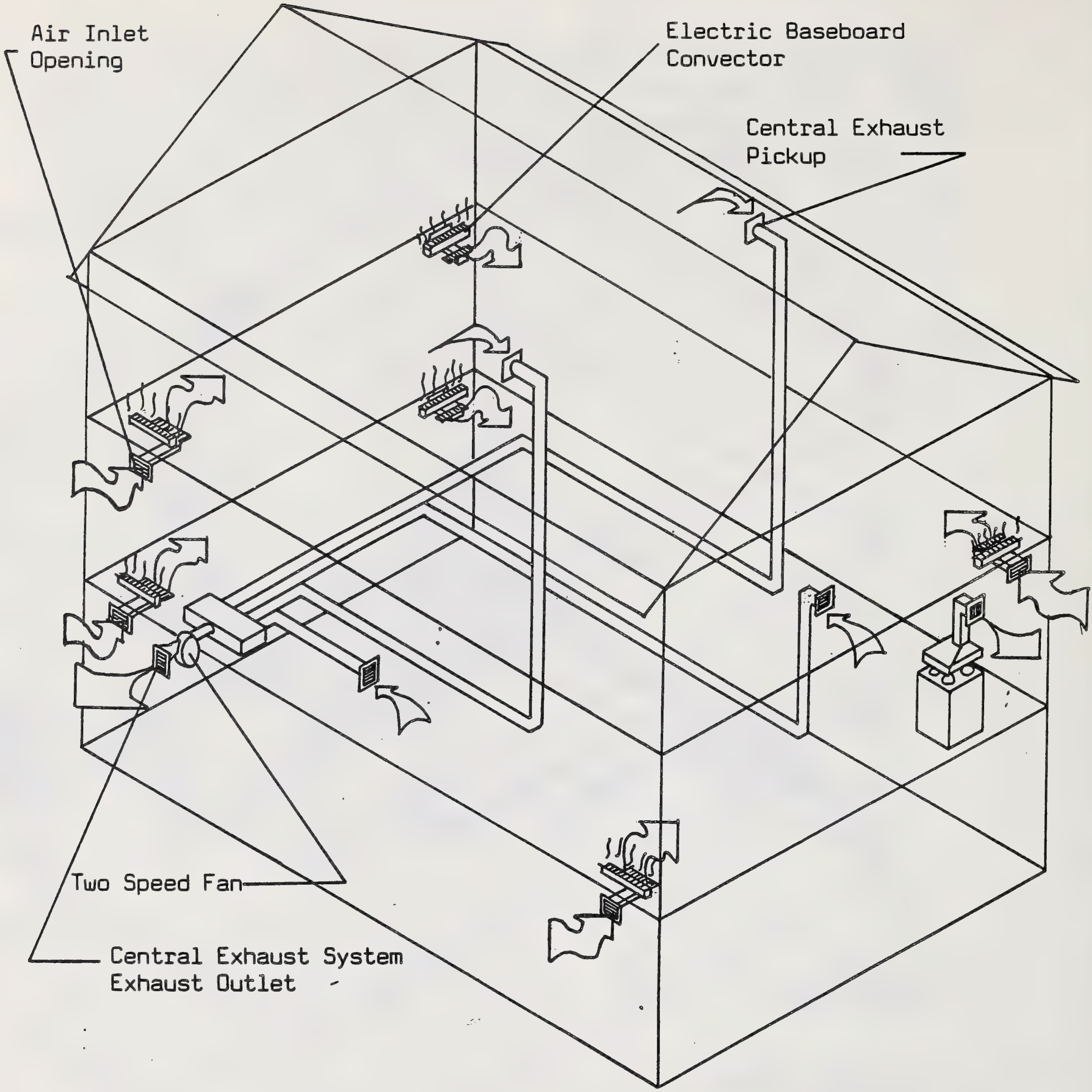

Air Inlet Opening
Electric Baseboard Convector
Central Exhaust Pickup
Two Speed Fan
Central Exhaust System Exhaust Outlet

Figure C-2 : Central Exhaust System
Multiple Intake Inlets - Floor Located
No Heat Recovery On Ventilation
Baseboard Electric Space Heating

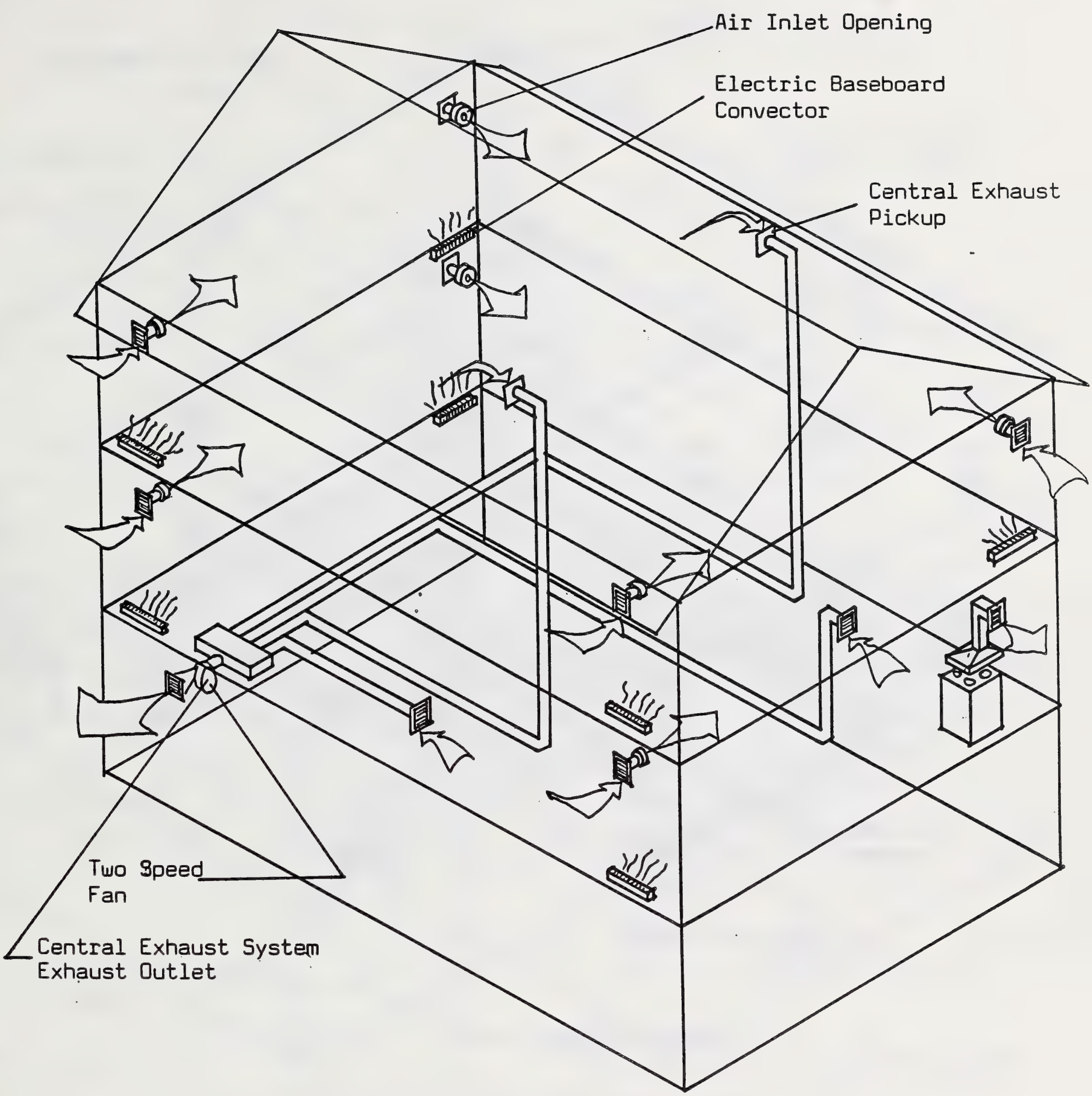

Air Inlet Opening
Electric Baseboard Convector
Central Exhaust Pickup
Two Speed Fan
Central Exhaust System Exhaust Outlet

Figure C-3 : Central Exhaust System
Multiple Intake Inlets - Wall Located
No Heat Recovery On Ventilation
Baseboard Electric Space Heating

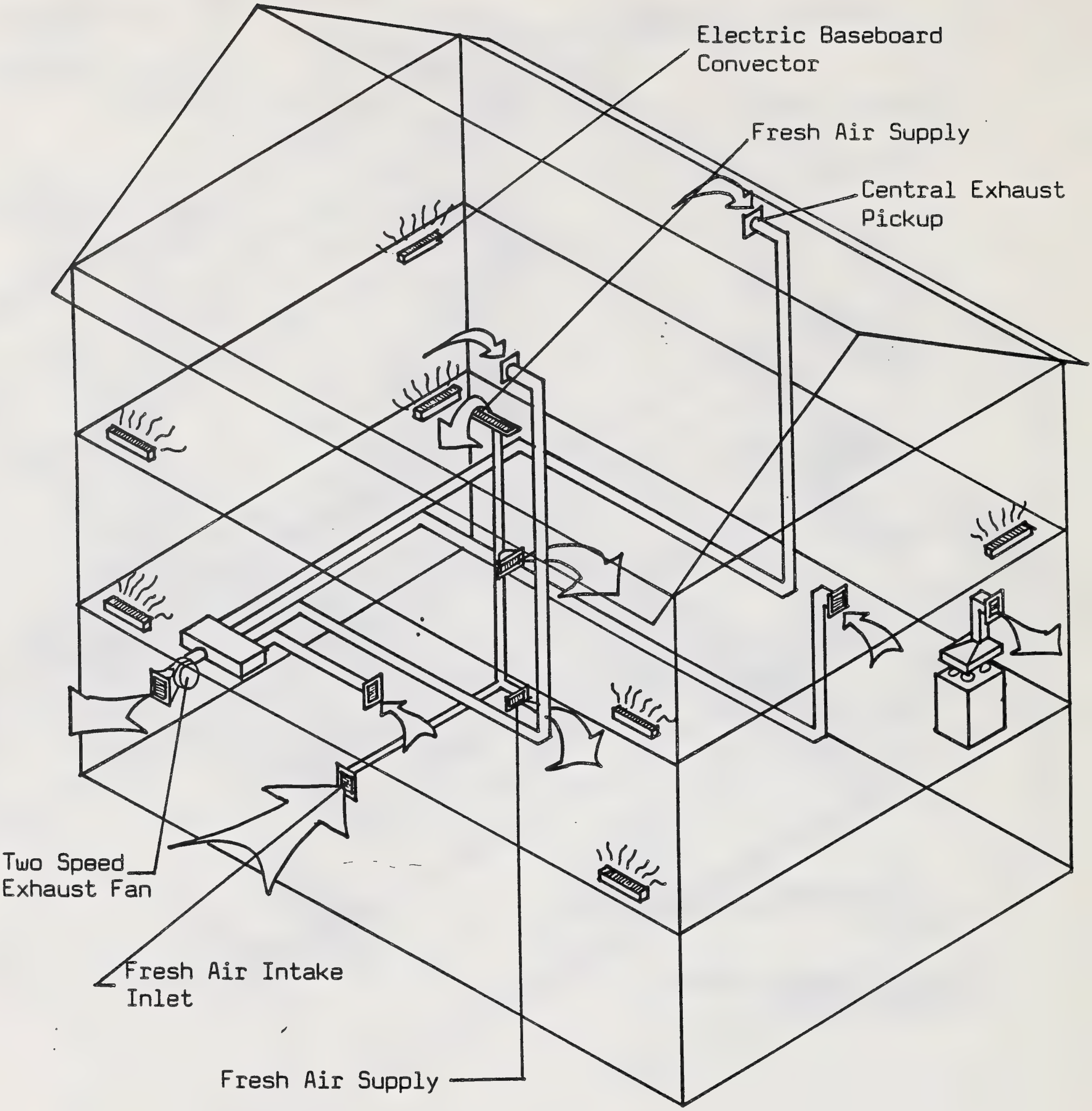


Figure C-4 : Central Exhaust System
Single Intake Inlet
No Heat Recovery On Ventilation
Baseboard Electric Space Heating

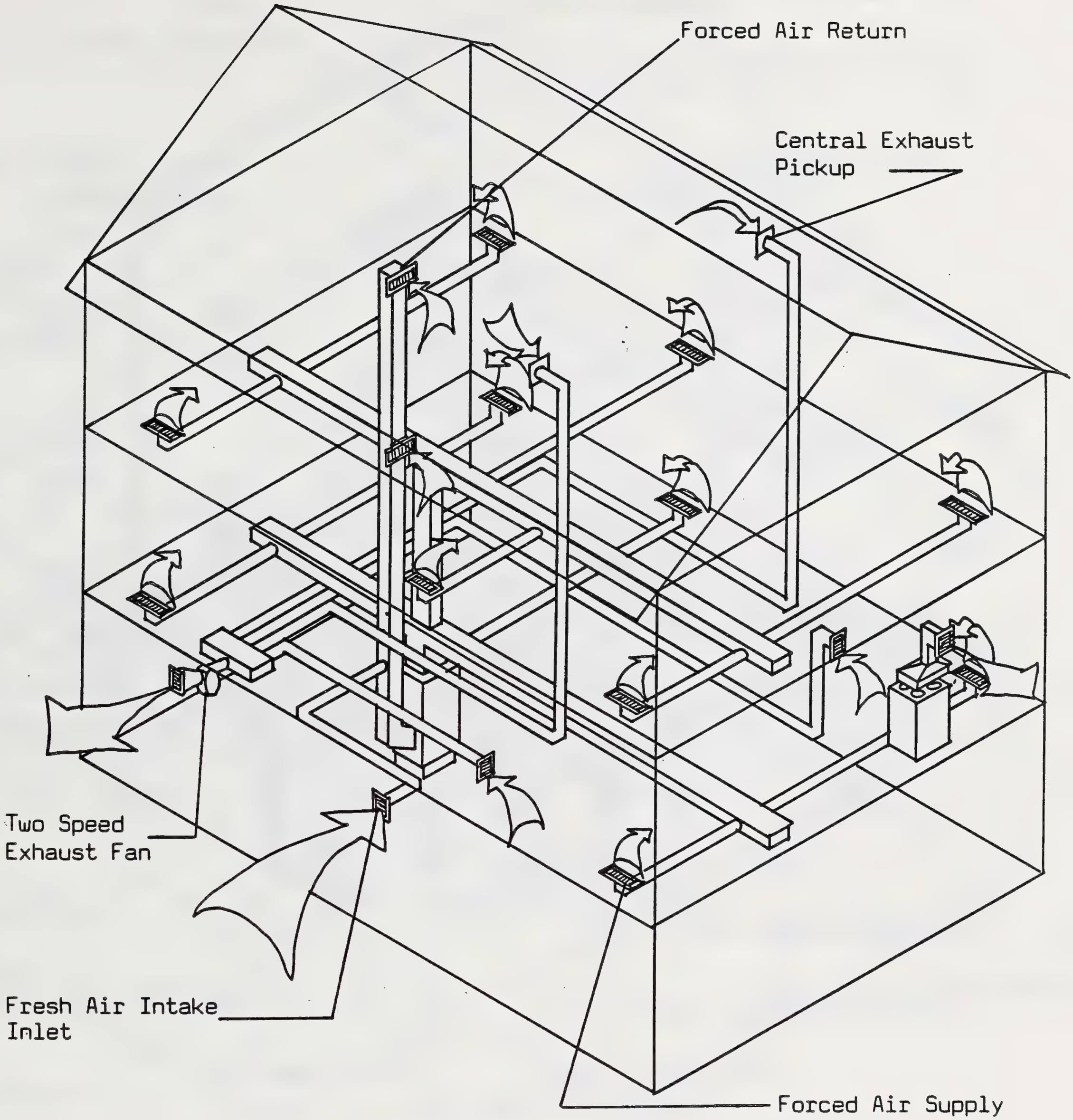


Figure C-5 : Central Exhaust System
Single Intake Inlet
No Heat Recovery On Ventilation
Forced Air Space Heating

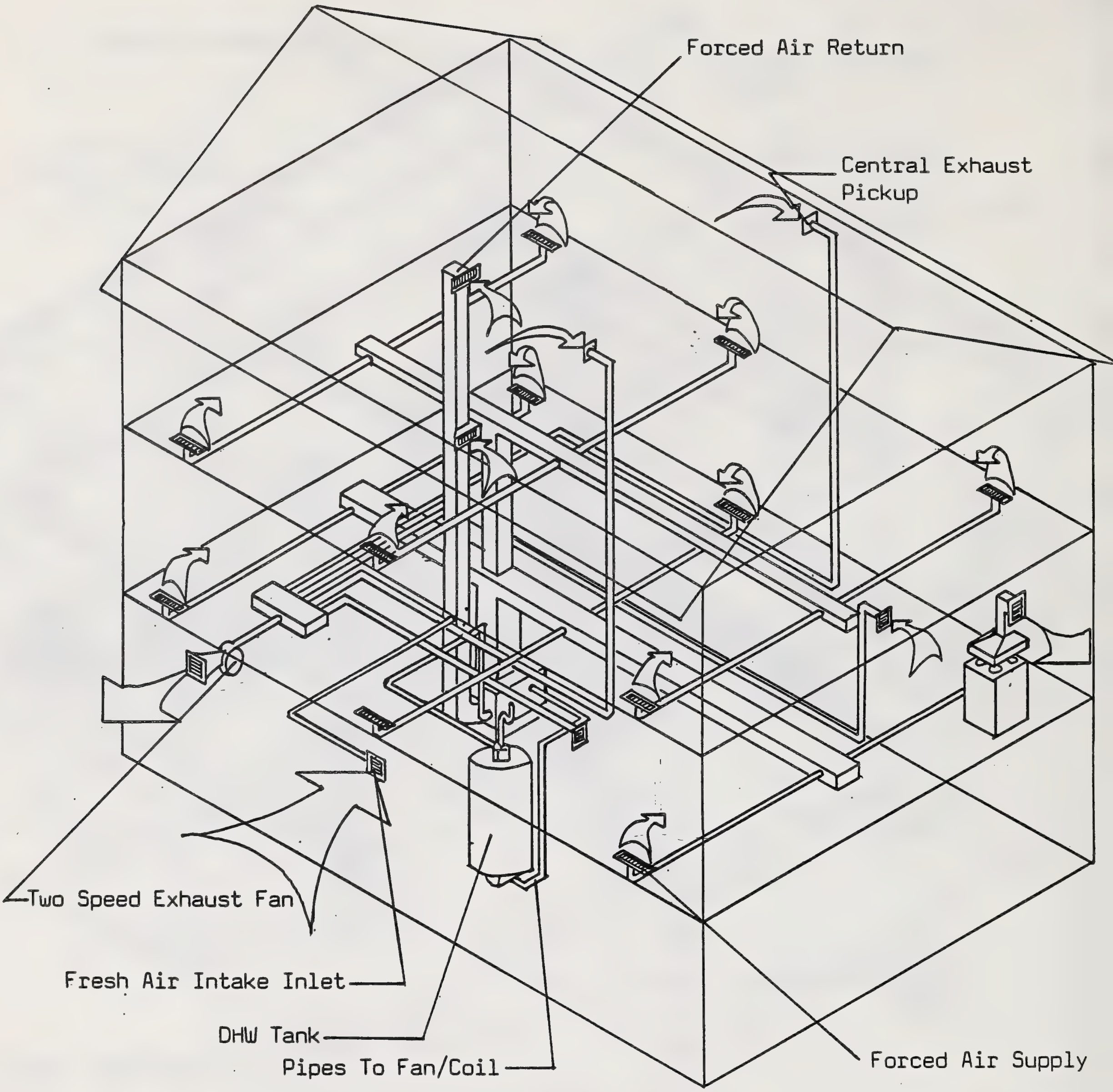


Figure C-6 : Central Exhaust System
Single Intake Inlet
No Heat Recovery On Ventilation
Forced Air Space Heating -
Fan Coil On DHW

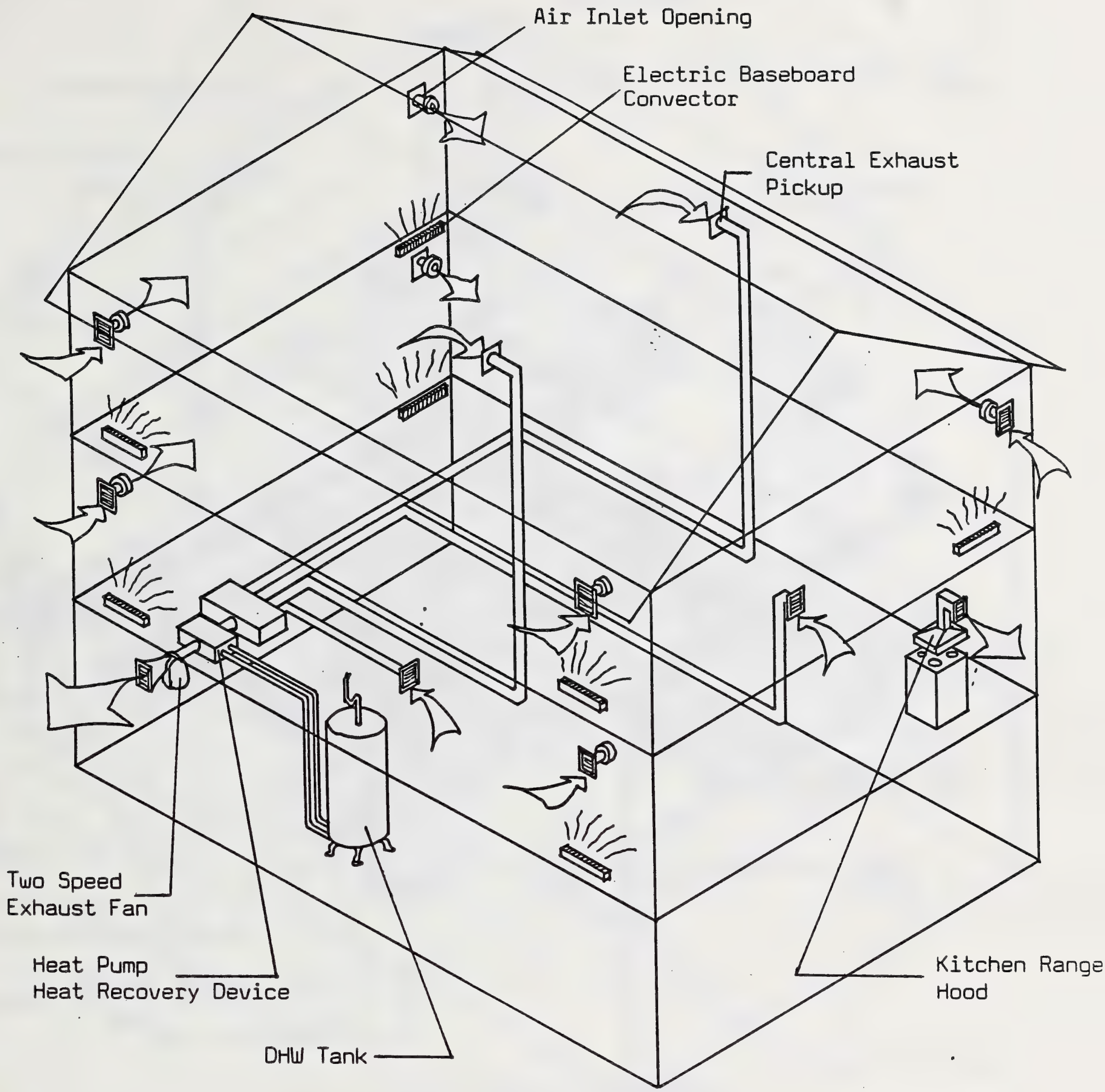


Figure C-7 : Central Exhaust System
Multiple Intake Inlets
Heat Recovery On Ventilation
Heat Pump To DHW
Baseboard Electric Space Heating

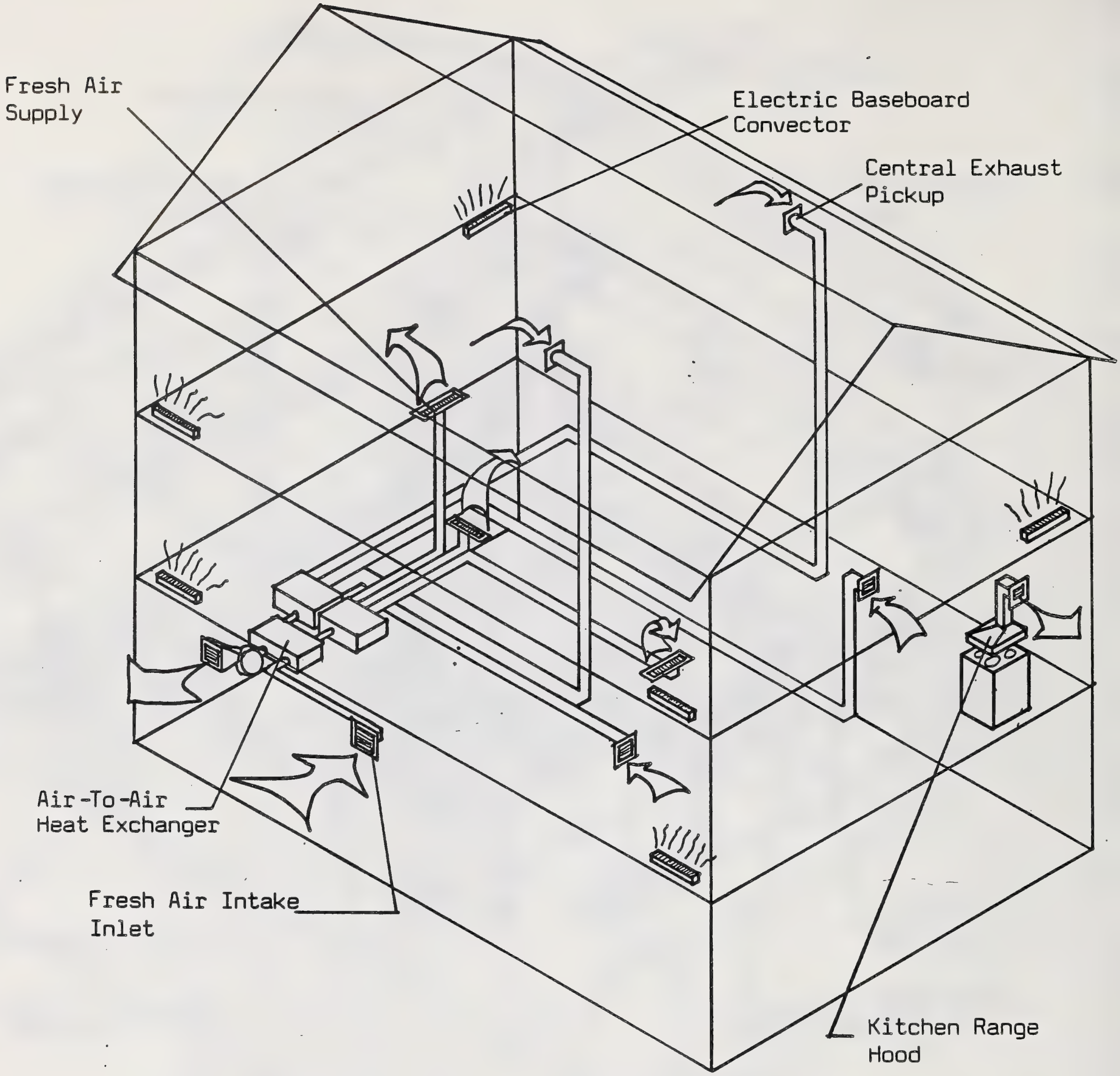


Figure C-8 : Central Exhaust System
Single Intake Inlet
Heat Recovery On Ventilation - ATAHE
Baseboard Electric Space Heating

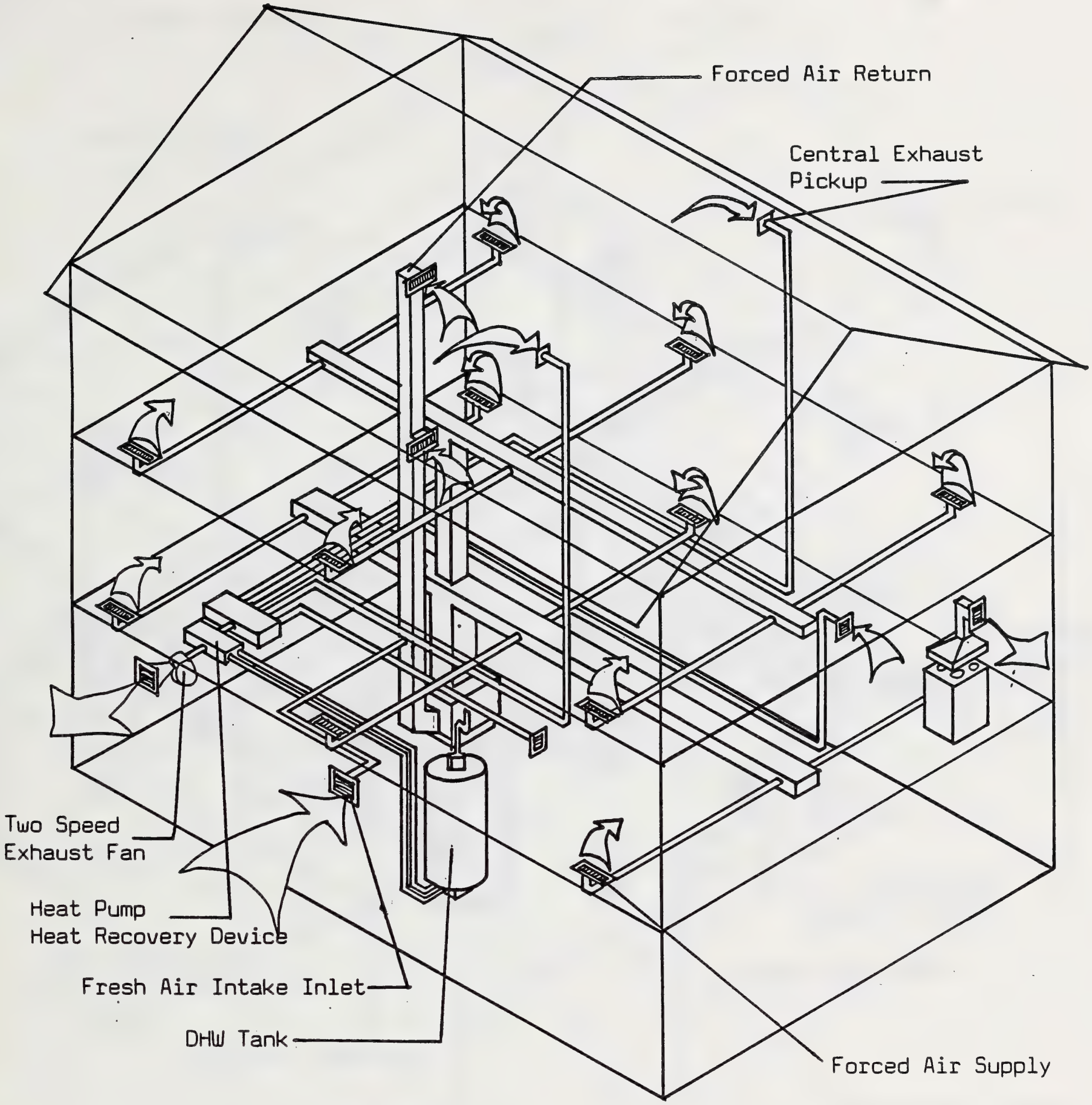


Figure C-9 : Central Exhaust System
Single Intake Inlet
Heat Recovery On Ventilation
Forced Air Space Heating

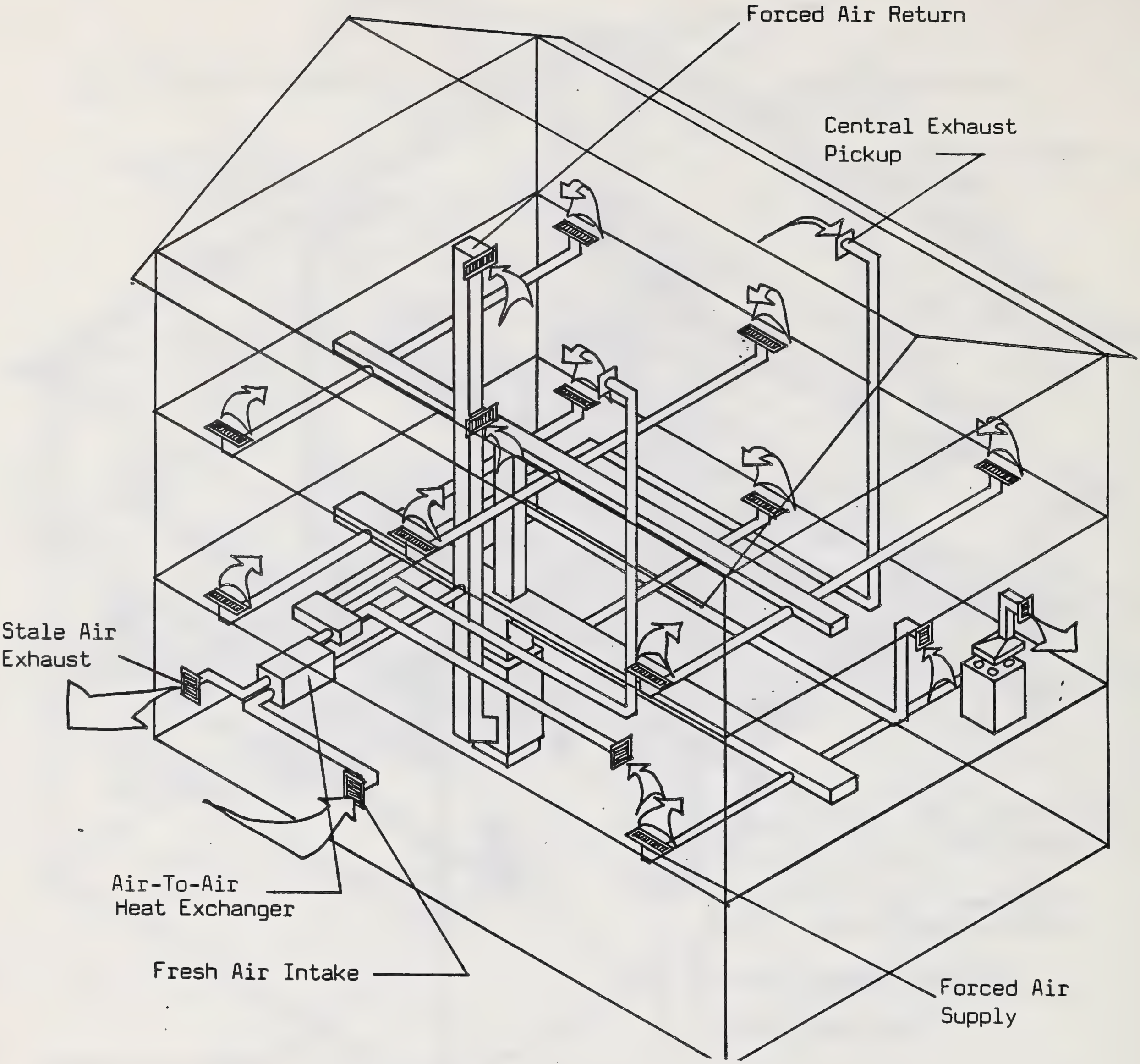


Figure C-10 : Central Exhaust System
Single Intake Inlet
Heat Recovery On Ventilation - ATAHE
Forced Air Space Heating

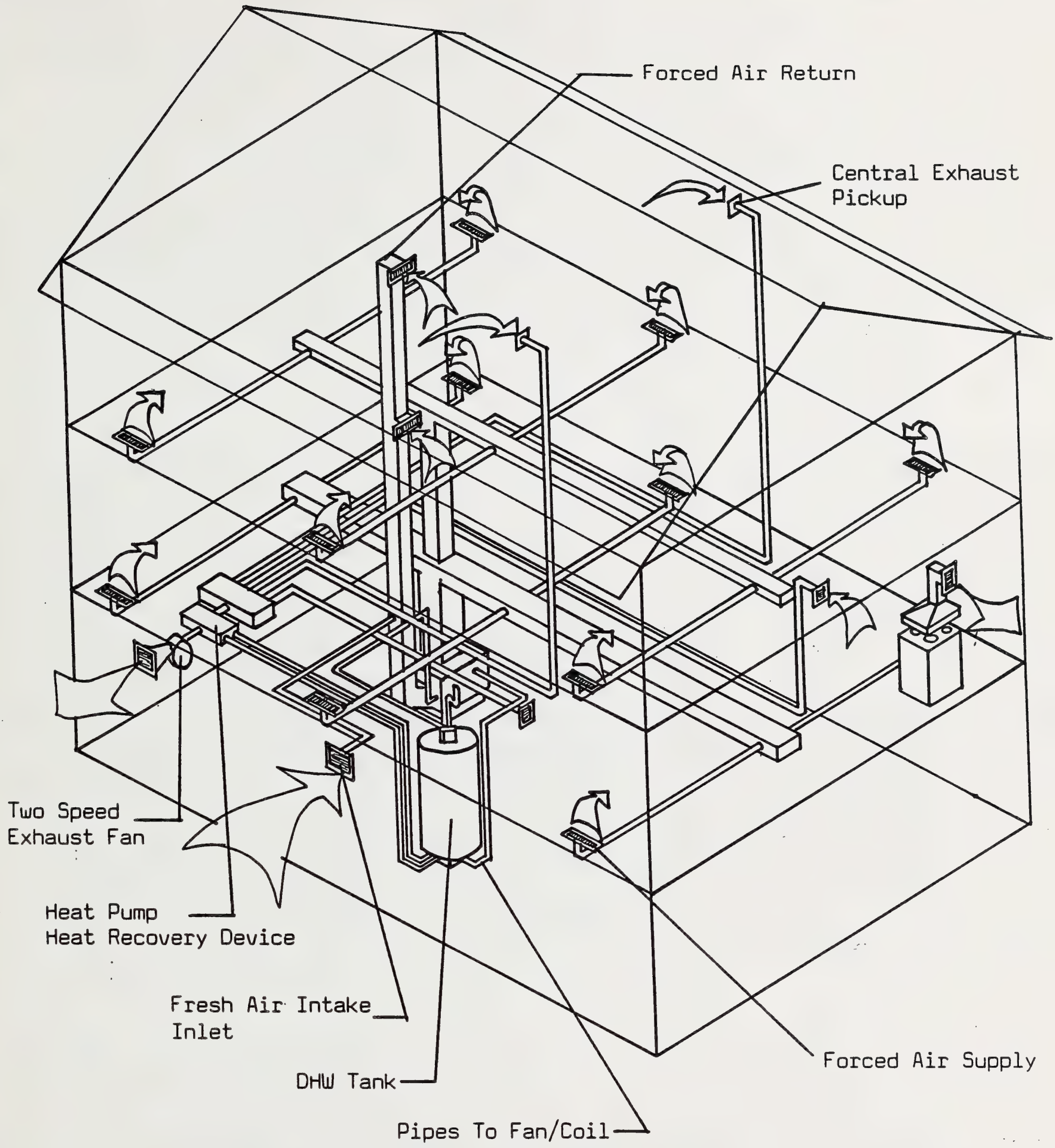


Figure C-11 : Central Exhaust System
Single Intake Inlet
Heat Recovery On Ventilation
Heat Pump To DHW
Forced Air Space Heating-
Fan Coil On DHW

APPENDIX D

APPENDIX D: CURRENT AIRTIGHT DRYWALL APPROACH (ADA) TECHNIQUES

A major component of a good building envelope may be the air barrier system. The Airtight Drywall Approach (ADA) uses gypsum board or drywall and various components of the building envelope as the air barrier system and a paint film as the vapour diffusion retarder.

The major function of the air barrier is not the prevention of vapour diffusion but, rather, the prevention of through-the-envelope air leakage. In addition to reducing energy consumption, the elimination of air leakage by the use of an air barrier system located towards the interior of the building envelope also eliminates exfiltration and the effect of interior/envelope cavity convective air movement, the major causes of condensation problems in heating climates.

The concept that four different methods, bulk water movement, capillarity, air movement and vapour diffusion, are responsible for moving moisture in and out of the building envelope has been greatly misunderstood. This misunderstanding has been partly due to the emphasis on vapour diffusion along with the unfortunate use of the term air/vapour barrier which couples two of the four independent moisture transport mechansims, air movement and vapour diffusion. Recently, builders have tried to use one material in the building envelope to serve both as an air barrier and a vapour barrier. However, it may be more practical to use one material as the air barrier and a different material as the vapour barrier.

Any material or system of materials may be used as an air barrier if the following requirements are met:

1. The material or system must be continuous.

2. The material or system must be impermeable to air allowing not more than 0.1 litres of air to pass through the system per second per square metre at 75 Pascals.

3. The material or system must be able to withstand the air pressure loads which act on it. That is, both the local minimum wind design loads and the influence of mechanical systems and stack action must be taken into account.

4. The material or system must be adequately stiff or rigid to maintain pressure equalization behind exterior cladding in order to control rain penetration under fluctuating wind pressures.

5. The material or system must be durable and easy to maintain over the service life of the building.

These five requirements are necessary and sufficient and any material or system which meets these requirements can be used as an air barrier.

Vapour barriers, to be effective, do not have to stop diffusion completely. The vapour barrier need only slow down or retard vapour diffusion and thus it is more correct to call it a vapour diffusion retarder. The vapour diffusion retarder does not need to be made of the same material as the air barrier and, unlike the air barrier, does not need to be continuous. Its only function is to retard vapour diffusion which acts independently from the movement of moisture laden air through the cracks and joints within or around building materials.

It has been calculated that the movement of water vapour through a 2 cm square hole as a result of a 10 Pascal air pressure differential is 100 times greater than the movement of water vapour as a result of diffusion through that same 2 cm square hole. The amount of vapour which diffuses through a vapour retarder is a function of area. That is, if 90 percent of the building envelope is covered with a vapour retarder, then the vapour diffusion retarder is 90 percent effective. In other words, continuity of the vapour diffusion retarder is not as significant as continuity of the air barrier and control of the other major moisture transport mechanisms, namely bulk water movement and capillarity. For instance, a paint film applied only on the interior exposed surface of the building envelope will act as a vapour retarder.

Continuity of the air barrier can be a major factor in controlling the movement of water vapour into wall and building assemblies. If the movement of moisture laden air into a wall or building assembly is eliminated movement of moisture by vapour diffusion is likely not significant.

Control of moisture movement using a continuous air barrier and an effective vapour diffusion retarder is more efficient than the use of an effective vapour diffusion retarder by itself. Confusion arises because most building codes clearly define the function of a vapour barrier but neglect to adequately define the function of an air barrier.

Building envelope design incorporating the previously defined concepts of air barriers and vapour diffusion retarders is illustrated by the Airtight Drywall Approach (ADA). It consists of interior cladding and structural elements assembled to act as a continuous air barrier and able to withstand wind and other mechanical loads. Because the air barrier is on the warm side of the building envelope, and is visible, it is exposed to a stable environment. Its airtight characteristics can be maintained inexpensively (after years of occupancy) by retouching seals after removing baseboards and mouldings and reapplying sealing compounds and or gasket materials. ADA focuses on how to make a gypsum board or drywall air barrier continuous in a conventional wood-frame house.

ADA uses little or no caulking. Caulking is replaced by compressible, square or round gaskets, which are used to seal wood framing members at the tops and bottoms of walls to make the air barrier continuous. The gaskets are closed cell vinyl or neoprene glazing tapes commonly used in commercial construction. Gaskets are faster to install than caulking as well as being cheaper, workable in cold weather and cleaner.

Framing carpenters install the gaskets between the framing members, and labourers usually install the gaskets between the drywall and the framing before the drywall is installed. The gaskets are secured with a staple gun.

In ADA, the drywall air barrier on the outside walls and ceilings is installed before the drywall on interior partitions. However, this is still done in one trip by the tradesmen. Thus, scheduling proceeds normally. The frame carpentry is done at one time as is the electrical rough-in.

The drywall is installed and taped in the usual manner, but it runs continuously behind interior partitions. This is done by framing the last stud of interior partitions approximately 40 mm back from the outside walls, allowing room for the drywall to be slid behind the interior partitions (Figure D-1).

Where interior partitions abut roof trusses, the partitions are framed with a single top plate. If single top plates are already being used on interior walls, then the interior partition studs are cut approximately 40 mm shorter. This leaves a space atop the partitions for sliding the ceiling drywall into place (Figure D-2). If it is necessary to utilize an interior load bearing wall to support roof trusses or if roof trusses are not used, then any interior load-bearing partitions are framed at normal height and the ceiling drywall is sealed to the top plate with gaskets (Figure D-18).

Between floors, the air barrier is kept continuous by gasketing between plates, rim joist, and subfloor (Figures D-4, D-7). Vertical joints in the rim joist are sealed as well. The rim joist is set toward the inside of the wall plates to allow room for insulation on the cold side of the air barrier (so condensation will not form here).

If the basement area is finished, then the air barrier in the basement area consists of the gypsum board or drywall on the exterior walls and the concrete floor slab (Figure D-3). The joint between the floor slab and the gypsum board or drywall is sealed by installing gasket material between the bottom edge of the perimeter drywall and the bottom plate, and between the bottom plate and the floor slab. If the basement area is unfinished, then the air barrier in the basement area consists of the concrete foundation wall and the concrete floor slab. The joint between the foundation wall and floor slab is sealed.

Damp-proofing is installed on the outside surface of the concrete foundation wall as well as between the cast concrete footing and the foundation wall to inhibit capillary action from drawing moisture into the foundation wall. It may be desirable or necessary to install damp-proofing on the interior surface of the concrete foundation wall to grade level in order to meet local building code requirements.

In climatic regions where long drying periods occur, such as western Canada, it is common practice to cast the foundation concrete walls so that the floor joists are embedded in the concrete. This approach provides support to the cast concrete foundation wall during the backfilling process. This practice is not recommended in climates which do not have sufficient drying potentials. The air barrier is made continuous by installing gasket material between the top edge of the embedded rim joist and the underside of the subfloor sheathing, and by sealing the bottom edge of the embedded rim joist to the cast concrete wall with an appropriate sealant or caulking material (Figures D-5, D-6).

Where floor trusses are used, air barrier continuity between storeys at subfloors is accomplished as in Figure D-10. The major point to note in Figure D-10 is the use of plywood as a rim joist or header or band joist in place of a standard wood joist. This is necessary to compensate for differential shrinkage rates between waferboards, plywoods and floor trusses as compared to typical floor joist material. Floor trusses, which for all intents and purposes, do not shrink, are combined with a waferboard or plywood rim joist or header. Standard floor joist materials, which do shrink as moisture contents decrease, are combined with standard rim joist or header materials which also shrink. A construction adhesive is used to provide a seal between the top of the plywood rim joist and the plywood subfloor in Figure D-10 as opposed to a gasket. A gasket was judged to be too difficult to install in this location. A wide gasket, of rectangular profile (Dow Sil Seal) is used at the bottom of the plywood rim joist as it is difficult to accurately position a narrow gasket directly under a narrow rim joist. A sealant is not recommended in this location, in order to allow for building frame movement.

Where floor joists run parallel to exterior perimeter walls and where claddings of different thickness, such as brick veneer meeting siding, intersect at subfloor level, details contained in Figures D-8 and D-9 are used respectively.

Air barrier continuity where exterior perimeter walls meet insulated ceilings is provided for as described in Figure D-11. The air barrier is made continuous at this location by virtue of the taped gypsum board joint between the wall gypsum board and the ceiling gypsum board. It should be noted that baffles of treated paper or other materials, are installed between the roof trusses directly in line with, and above the exterior perimeter wall top plates in order to limit the deleterious effects of wind washing or blow-through in which wind can serve to short-circuit thermal insulation and lead to local chilling of the interior cladding which often results in high interior surface relative humidites and hence mould and mildew growth. It is important to note that a perfect air barrier located on the interior of an exterior wall will not eliminate mould and mildew formation as it does not prevent wind washing. Gable walls are constructed as in Figure D-12.

At window and door openings, the drywall is returned directly to the window or door frames and the resultant joint caulked. The caulking is either painted or capped with a wood moulding (Figure D-13). In cases where wood extension jambs are used, the drywall is sealed to the jamb extension in a similar fashion (Figure D-14). These seals are easy to maintain over the service life of the building.

The air barrier is made continuous at exterior corners by taping together the gypsum board or drywall sheets (Figure D-15). The use of drywall clips at corners, instead of backup studs for nailing support, results in several benefits. An extra degree of freedom of movement is provided for the gypsum board or drywall. This reduces the incidence of drywall cracking. Furthermore, since less wood is used in corner construction, the space that would normally be taken up by the wood is replaced by insulation. Since the corner is warmer, there is less chance of mould and mildew growth, provided, of course, that wind is not allowed to short-circuit the insulation by blowing through the exterior insulating sheathing or through the fibreglass batts.

Cantilevered floor construction, typically encountered at second floor subfloors, is facilitated by the use of the construction details presented in Figure D-16 and Figure D-17. In Figure D-16, where intersecting floor joists cross over a perimeter exterior wall, wood blocking or blocks of rigid, non-air permeable, insulating sheathing are inserted into the joist spaces and sealed around their edges with caulking to provide for air barrier continuity. The air barrier over the cantilever portion of the subfloor therefore becomes the subfloor sheathing. Seams in the subfloor sheathing are sealed with subfloor adhesive. In Figure D-17, where floor joists are aligned parallel to a lower perimeter exterior wall, a floor joist is positioned directly over the lower perimeter exterior wall and gasketed similar to a typical rim joist or header. Since the subfloor sheathing is the air barrier over the cantilever portion of the subfloor, seams in the subfloor sheathing are sealed with a subfloor adhesive as in Figure D-16.

Attic hatchs constructed penetrating the air barrier and post supports are decribed in Figure D-19 and Figure D-20 respectively.

Where a split level dwelling is constructed, horizontally installed blocking between vertical stud members is used to make the air barrier continuous between the gypsum board or drywall ceiling on the lower level and the gypsum board or drywall on the upper level exterior wall. This blocking is caulked between the vertical stud spaces and gaskets are installed in a continuous fashion on both sides of this blocking to provide for the air barrier transition between the drywall on the insulated ceiling and the drywall on the upper exterior wall (Figure D-21).

Where plumbing penetrates the air barrier such as in the ceiling, the pipe is clamped to wood blocking behind the drywall and the pipe then sealed to the drywall. Where large-diameter vents penetrate a ceiling, an expansion joint is recommended. With smaller pipe, any movement can be accommodated by offsetting the pipe horizontally a few feet in the stud bays before penetrating the roof (Figure D-22).

It is recommended that electrical outlets and wall switches be placed, where possible, on interior walls. Where it is necessary to place electrical switches and outlets on exterior walls, these are installed in a conventional manner. The gypsum board or drywall air barrier is sealed to the electrical outlet by mudding the gypsum board directly to the electrical outlet and by installing a compressible gasket directly under the cover plate of the outlet or switch (Figure D-23). Such gaskets are currently being used in the retrofit air sealing industries. It is also recommended that outlet boxes without openings be selected, such as sealed plastic outlet boxes. Wires penetrating these boxes should also be caulked to the box.

Alternatively, it may not be necessary to penetrate the gypsum board or drywall on exterior walls if low-profile, surface mounted boxes are located at baseboard level. Electrical wires are run directly down from the surface-mounted electrical box, through the floor sheathing and into the floor joist space. In this manner, no wiring penetrates the gypsum board or drywall air barrier. Local code requirements may limit the applicability of this surface mounted approach.

Where possible, it is recommended that the number of ceiling fixtures be limited in insulated ceilings. It may be possible to replace switched ceiling lights in upper storey bedrooms with switched wall plugs, with the wall plugs placed on interior partitions. Should ceiling outlets on insulated ceilings be necessary, a wire can be dropped through a pre-positioned piece of wood blocking. A single hole is then left in the gypsum board for this wire, and the penetration is sealed with an appropriate sealant. A surface-mounted, low-profile, shallow saucer electrical box is then installed (Figure D-24). When using this approach only one wire can be installed in each saucer outlet and switching connections must be done at the wall-mounted boxes. This requires minor modification of conventional electrical wiring procedures.

Electrical panels installed in basements are mounted on a plywood or waferboard sheet. The basement gypsum board or drywall is installed to form a butt joint between this plywood or waferboard backing for the electrical panel and the resulting seam is sealed (Figure D-25). Electrical wires running to interior partitions are run to the interior surface of this plywood or waferboard backing. The wiring for electrical outlets placed in the exterior walls in the perimeter basement walls is run through the plywood of waferboard backing. Sealing is required only where the electrical wire penetrates the plywood backing at this location. It is also recommended that an appropriate sealant be installed both in the main conduit supplying electrical power to the building and around the exterior of the pipe conduit itself (Figure D-26).

Electrical wires running from switches or outlets found on interior walls are never run through exterior walls to the electrical panel. Instead, these wires are routed down inside the interior walls and into the subfloor. They never penetrate the air barrier, and hence, do not need to be sealed in any manner.

If it is necessary for electrical wires to enter an exterior perimeter wall, they can do so only at the bottom plate of the exterior perimeter wall, either from the subfloor beneath or from along the bottom plate of an intersecting interior partition wall. Where these wires enter the exterior perimeter wall they are caulked to the framing or to the perimeter gypsum board (Figures D-26, D-27). An example of such an occurance is where a wall switch is mounted on an interior partition wall and it controls a ceiling light installed on an insulated ceiling. It is necessary to route the electrical wire from the wall switch along the intersecting interior partition wall to the exterior perimeter wall, and enter this exterior perimeter wall at the bottom plate level. The electrical wire would not be routed directly up into the ceiling space and subsequently interfere with gypsum board installation. By routing the electrical wires in the manner described, ceiling gypsum board can be installed in a continuous manner over the tops of interior partition walls and vertically along exterior perimeter walls past intersecting interior partitions without interference from the electrical wires. A small notch at the baseboard level may be required when installing a gypsum board sheet located on exterior perimeter wall where an electrical wire enters the exterior perimeter wall from an intersecting interior partition.

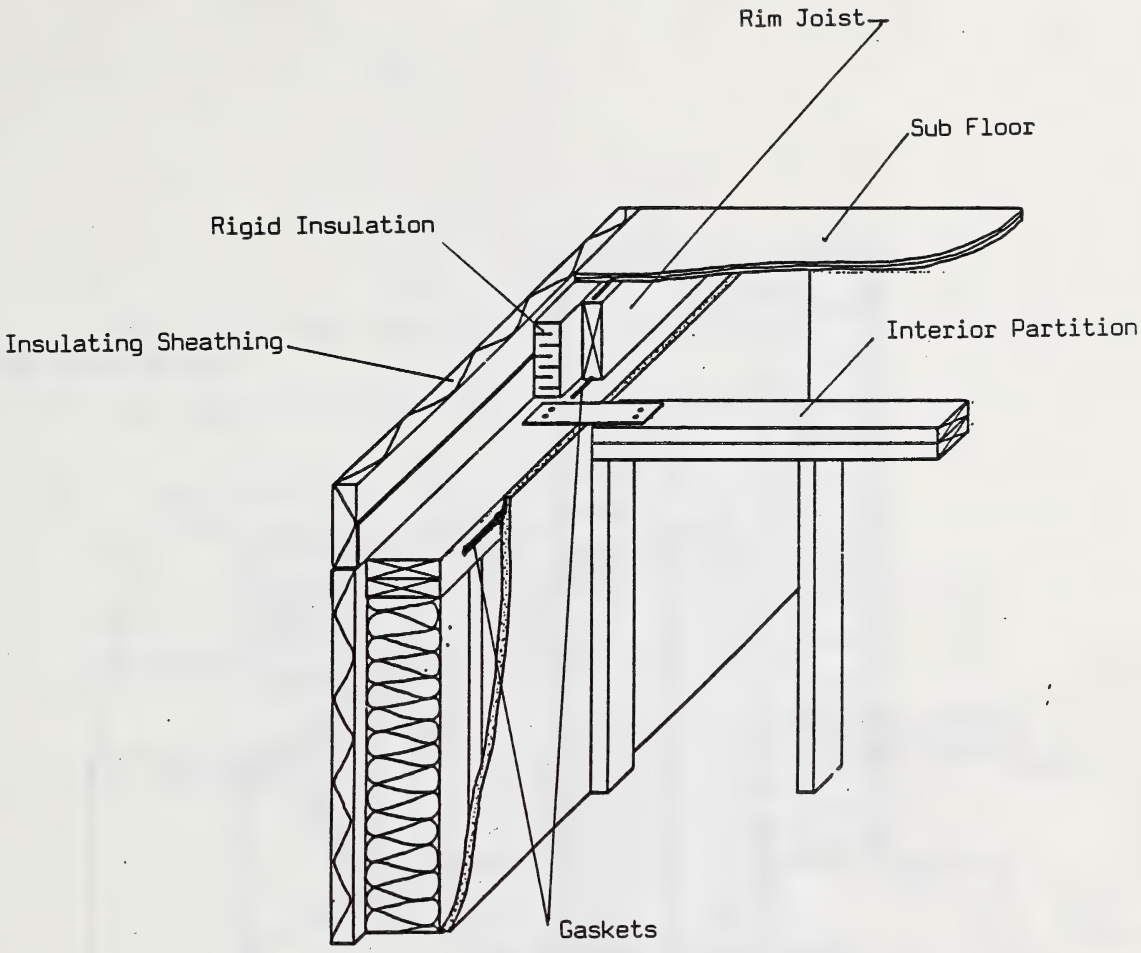


Figure D-1 : Intersecting Interior Wall

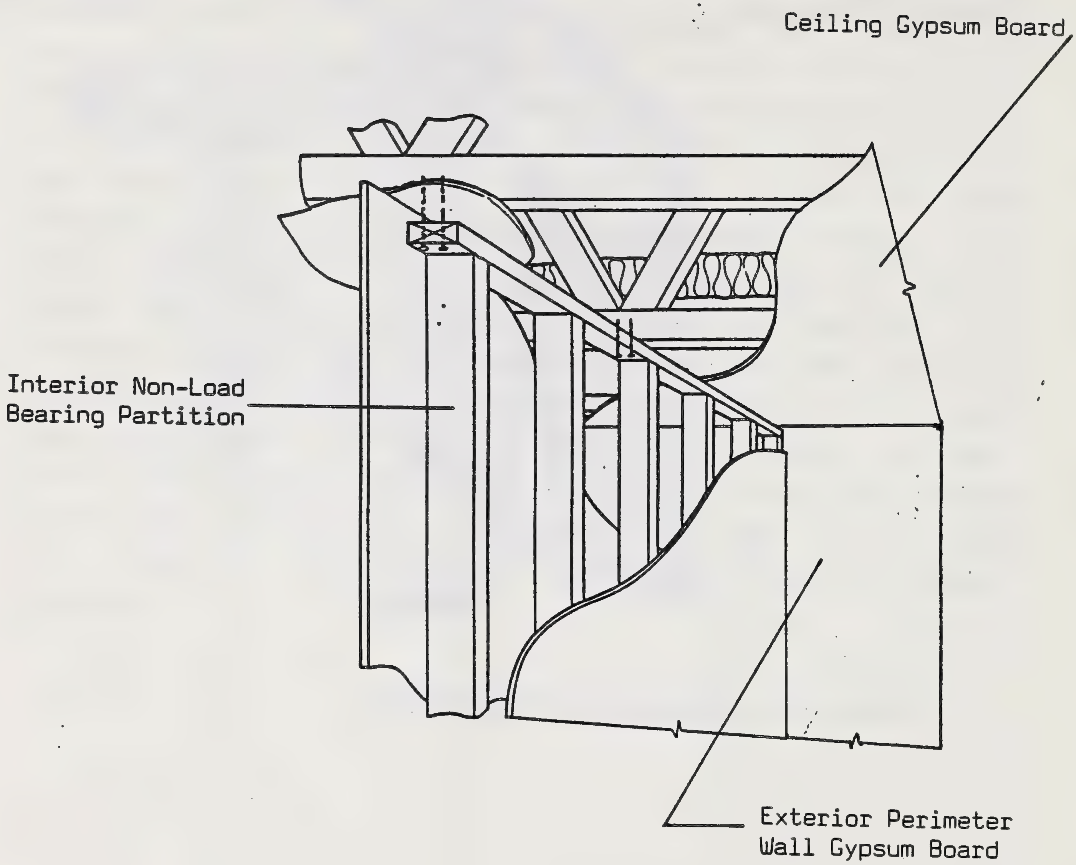

Ceiling Gypsum Board
Interior Non-Load Bearing Partition
Exterior Perimeter Wall Gypsum Board

Figure D-2 : Interior Wall Intersecting Insulated Ceiling

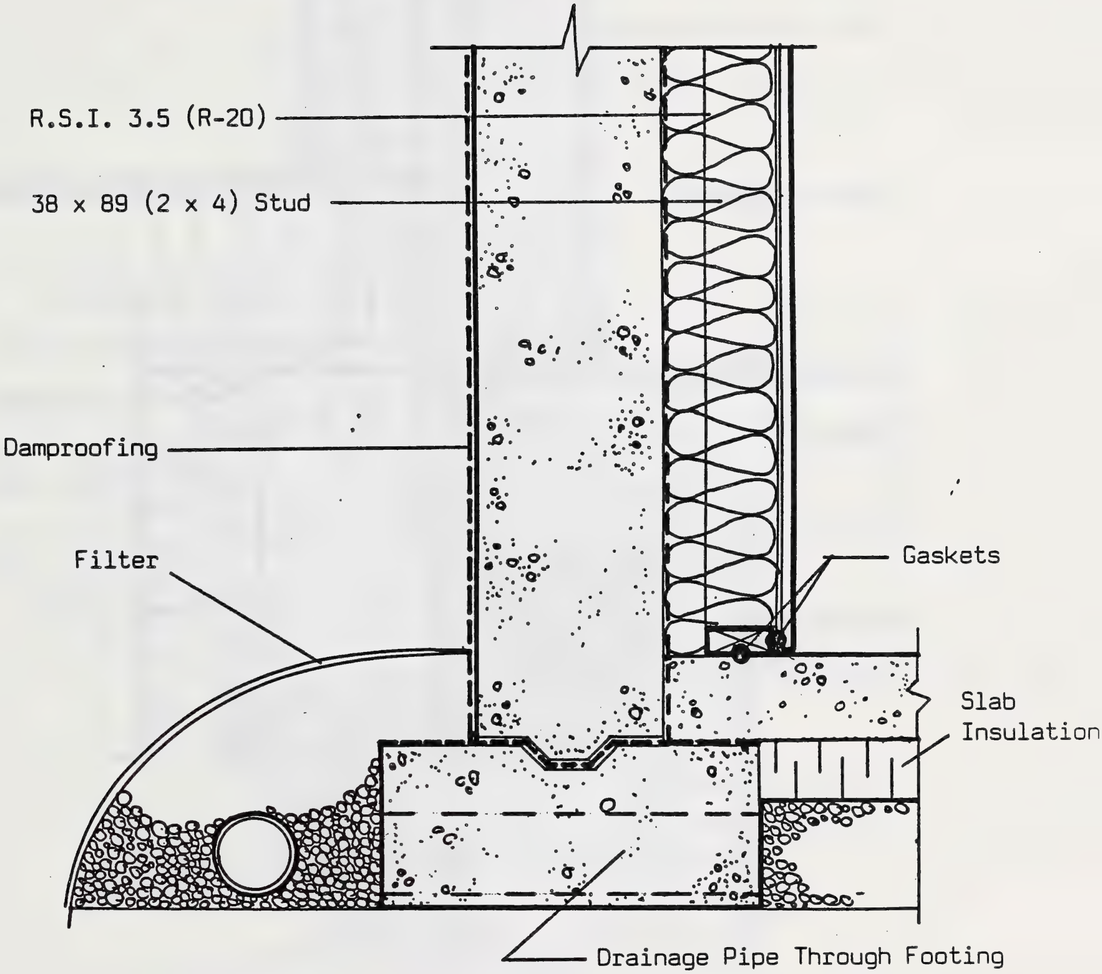


Figure D-3 : Footing Detail

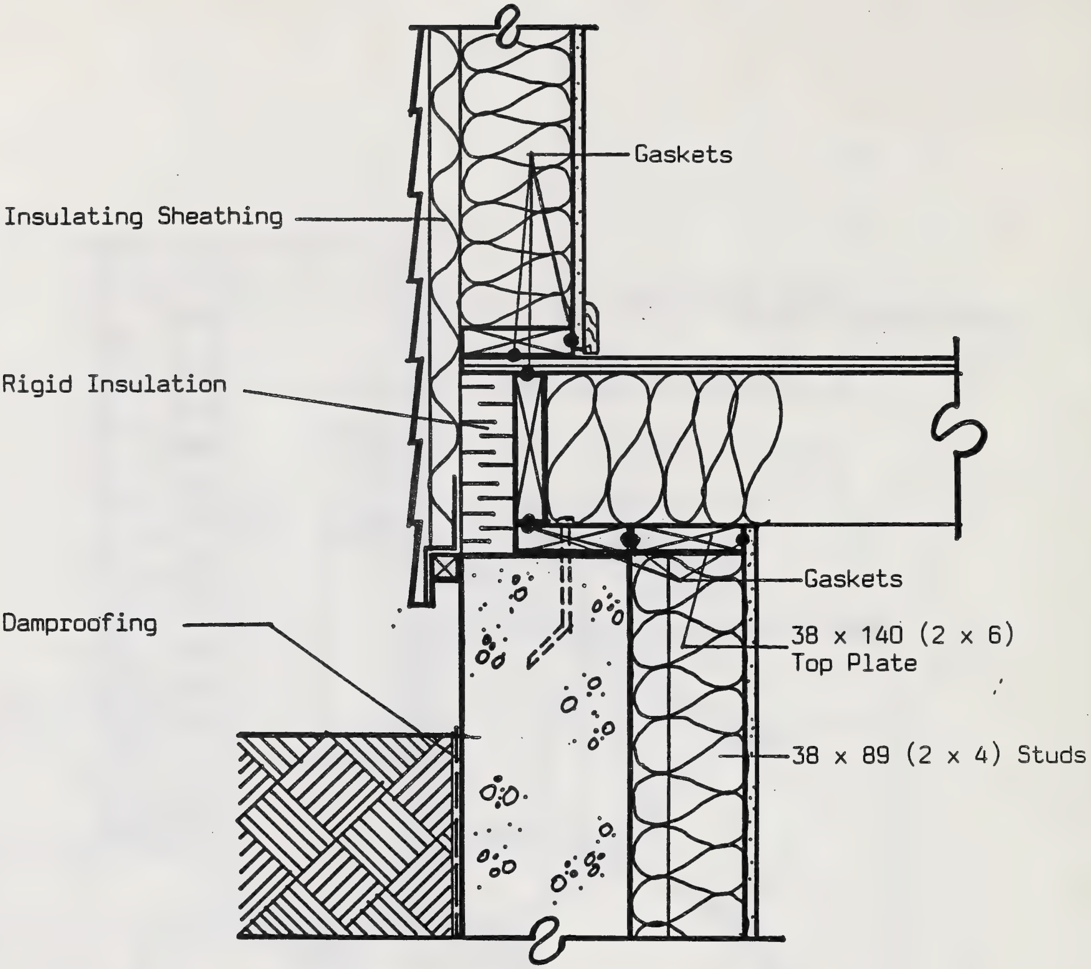


Figure D-4 : Subfloor At Grade

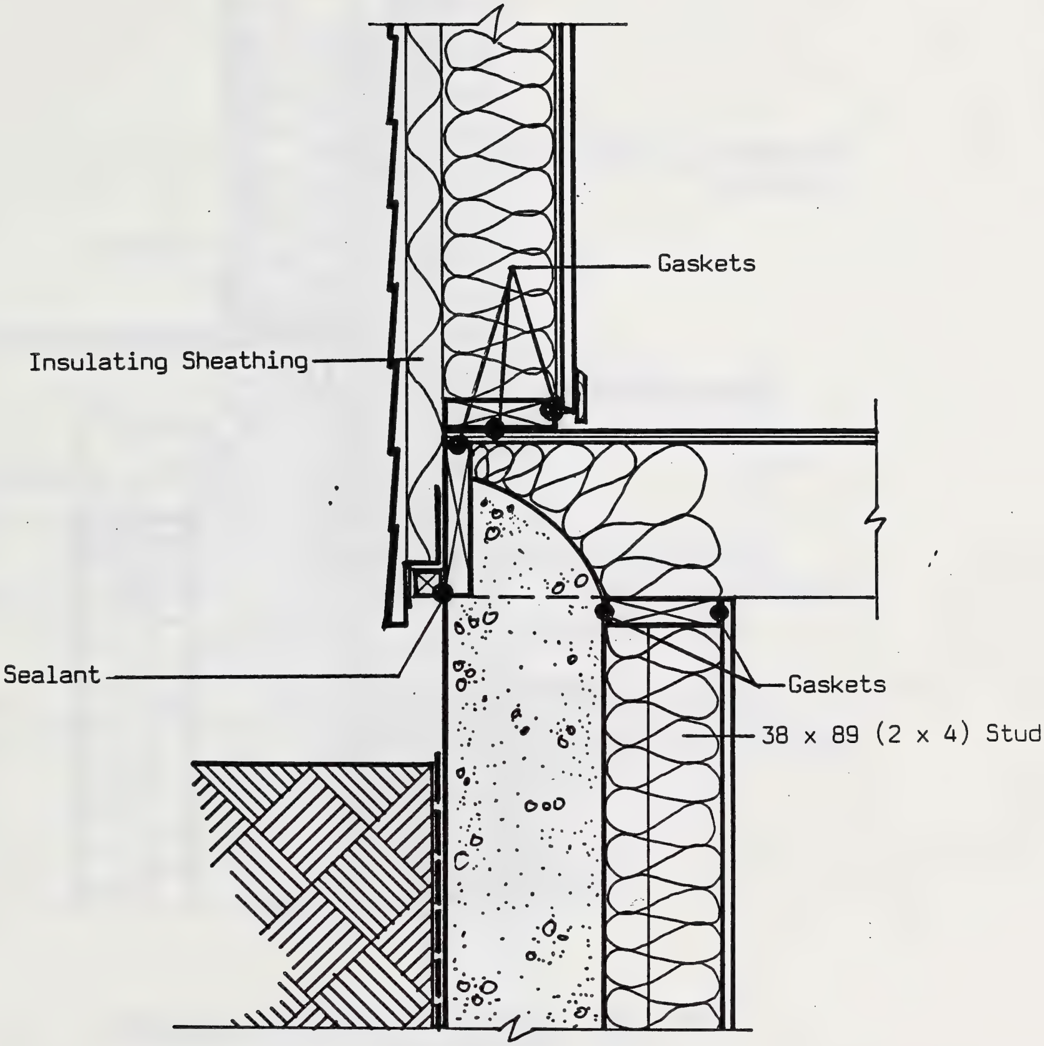


Figure D-5 : Subfloor At Grade - Western Detail

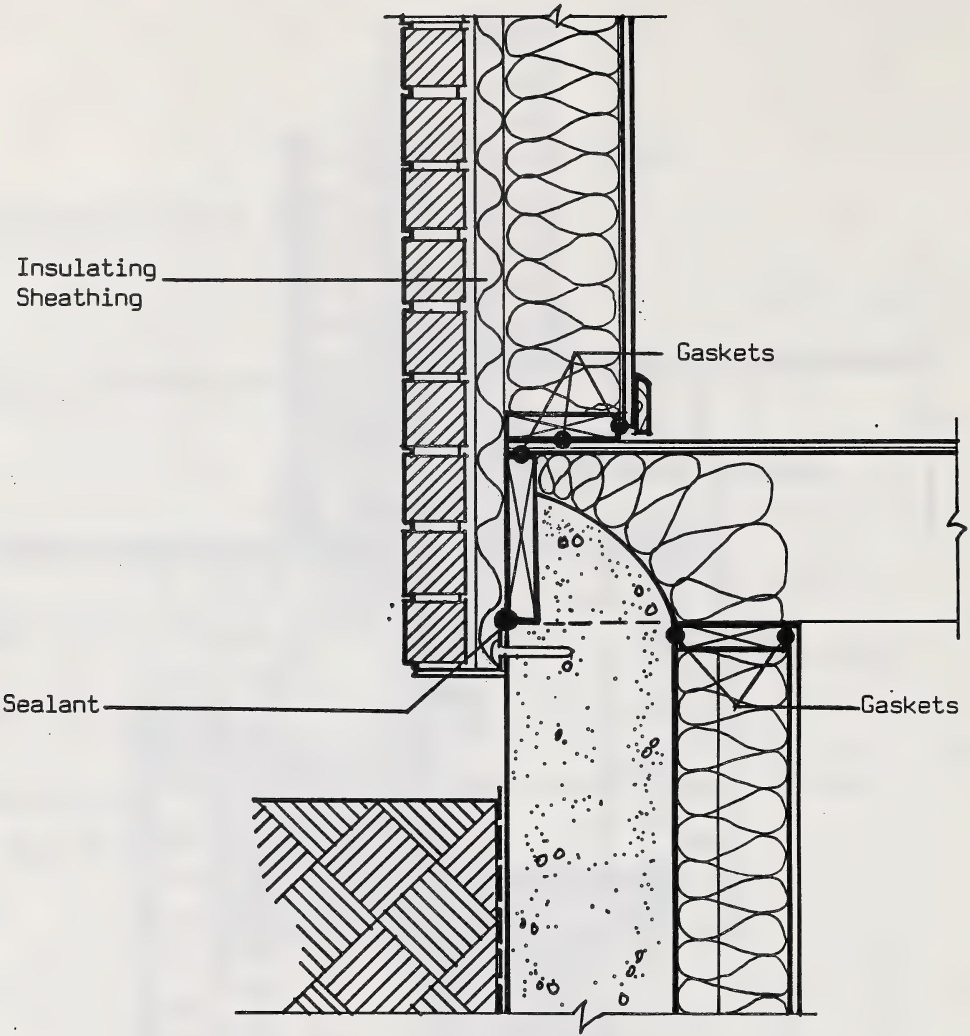
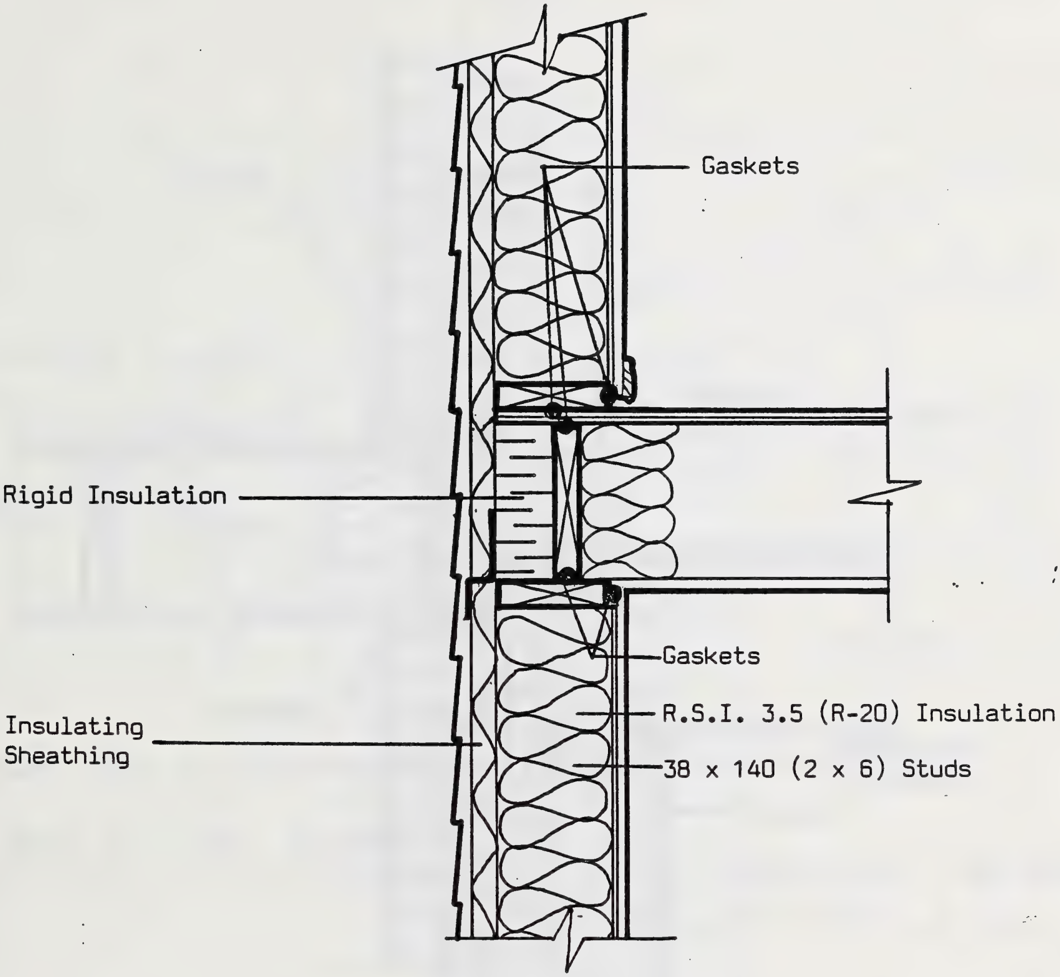


Figure D-6 : Subfloor At Grade Western Detail
Brick Veneer



Firgure D-7 : Second Floor Sub Floor

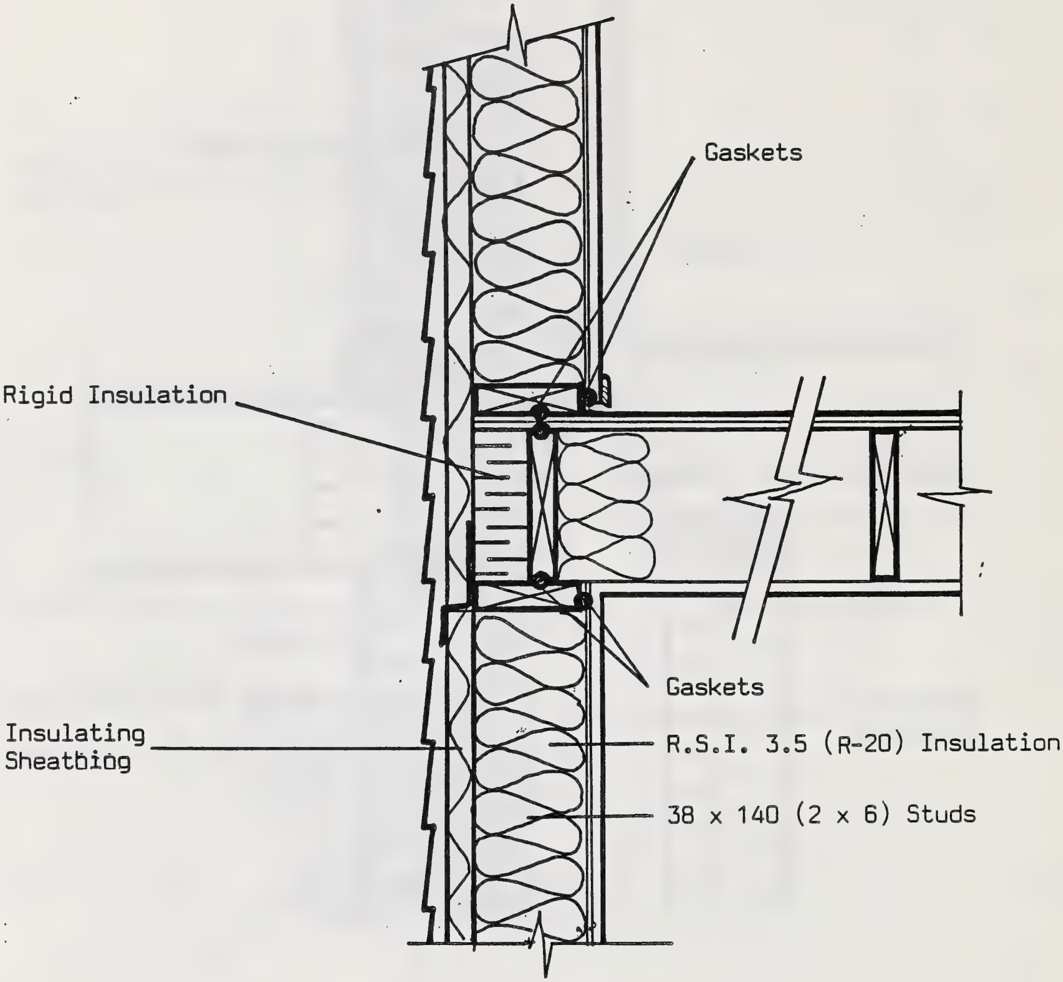


Figure D-8 : Second Sub Floor
Parallel Joists

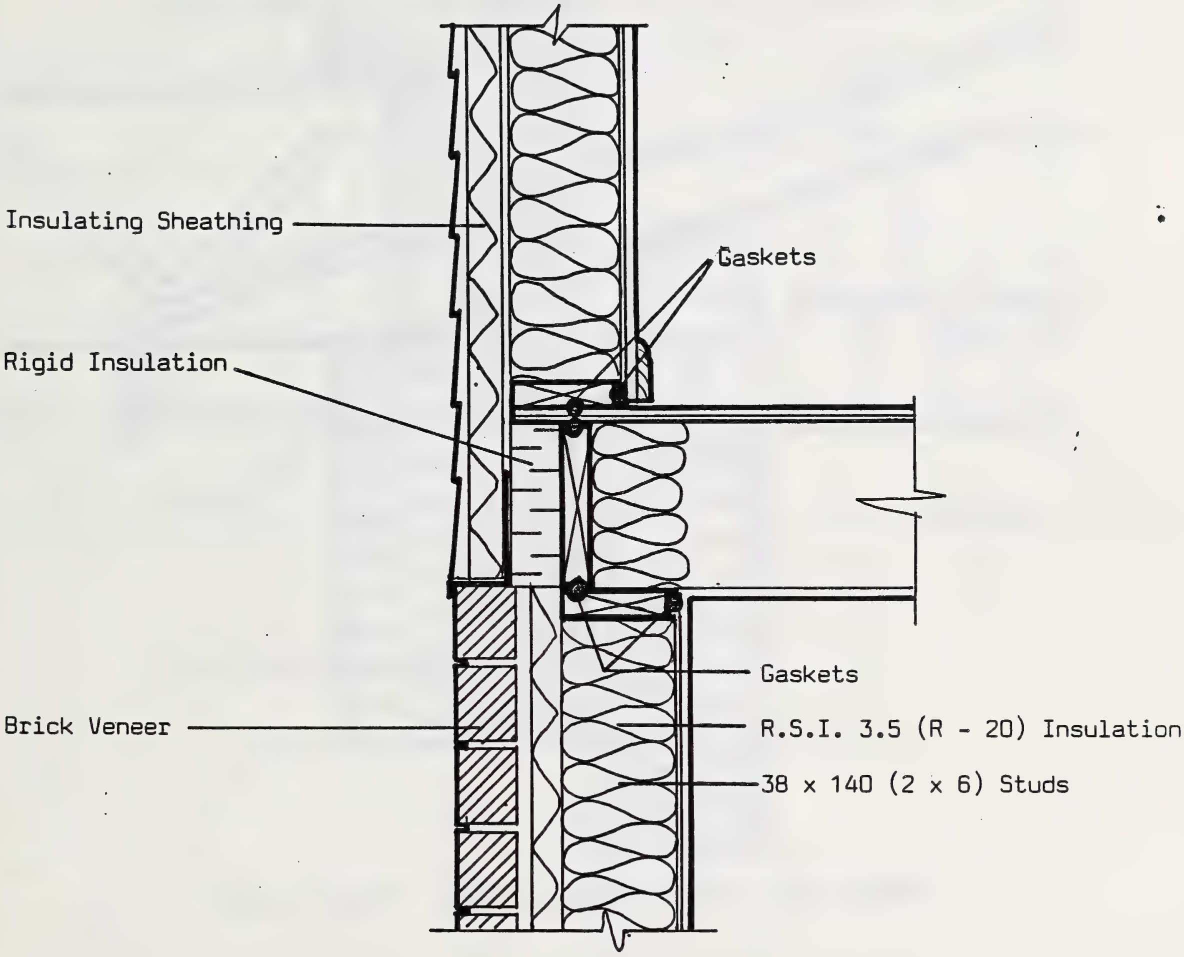


Figure D-9 : Second Sub Floor
Brick Veneer/Siding Transition

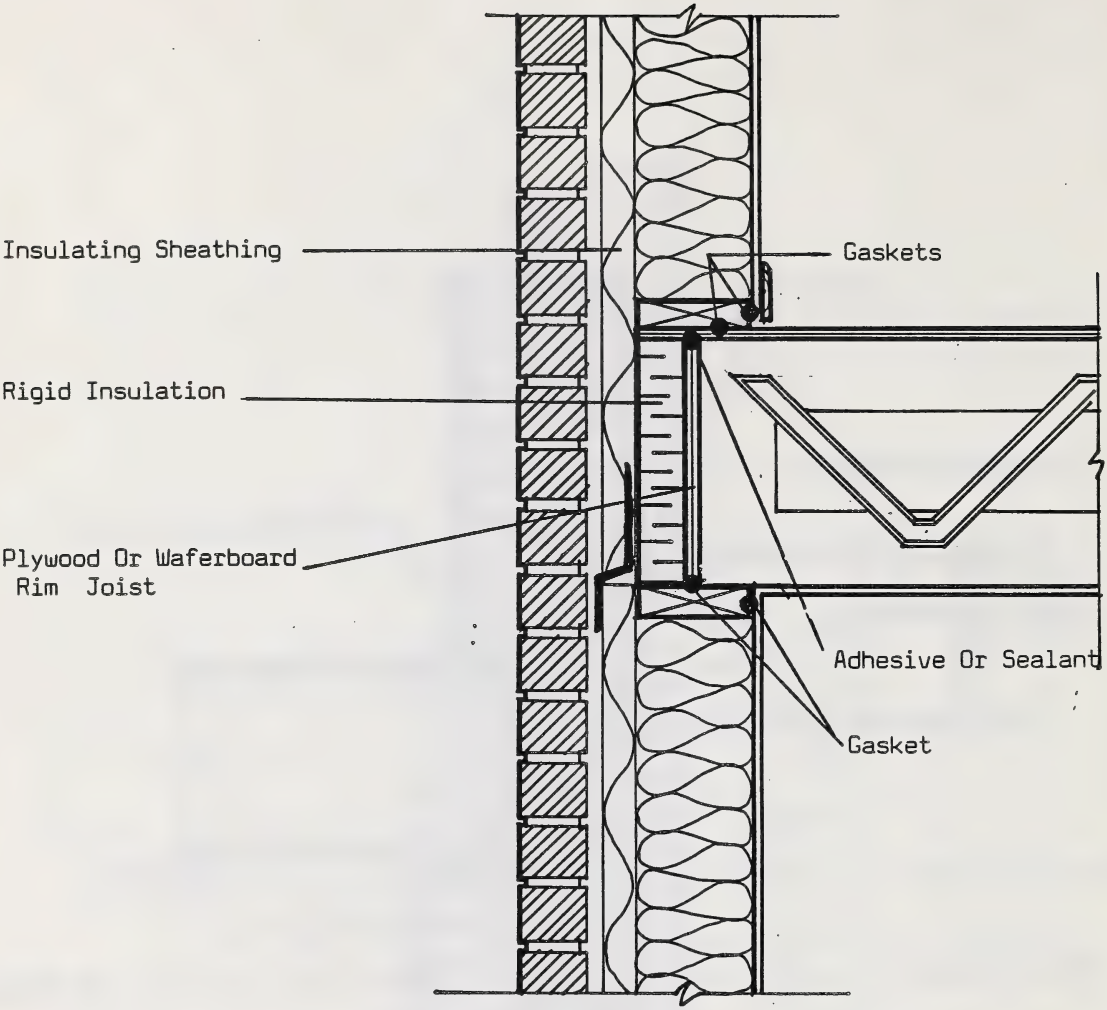


Figure D-10 : Second Floor Subfloor - Floor Trusses

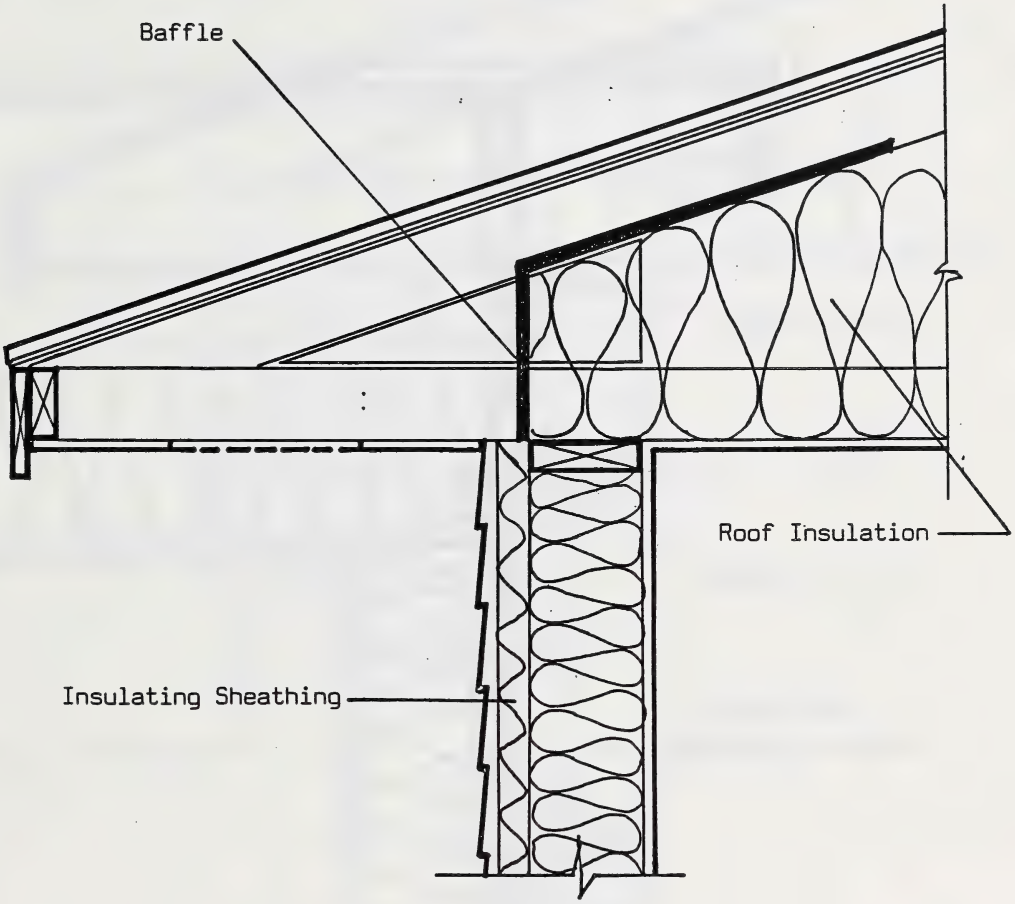


Figure D-11 : Roof/Ceiling Interface

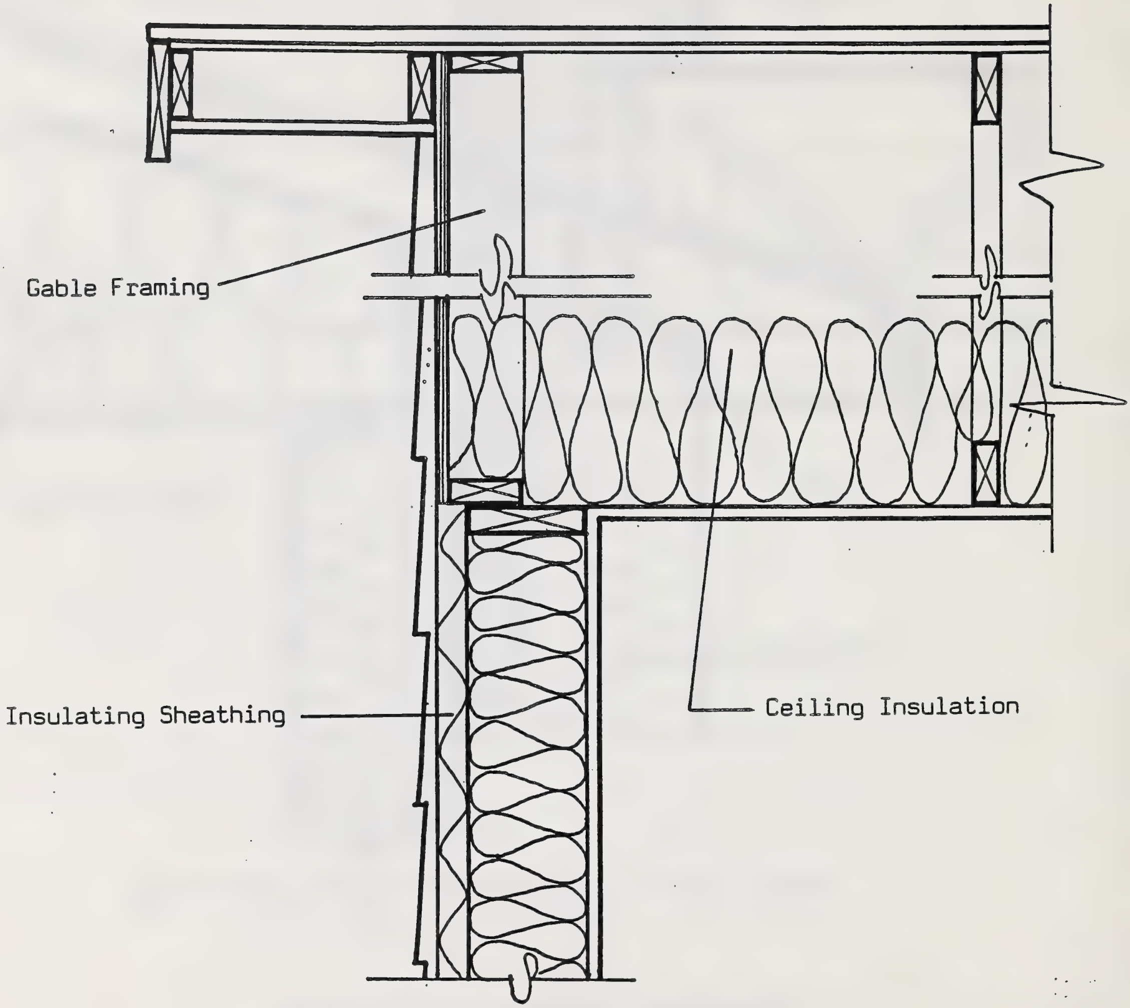


Figure D-12 : Gable Construction

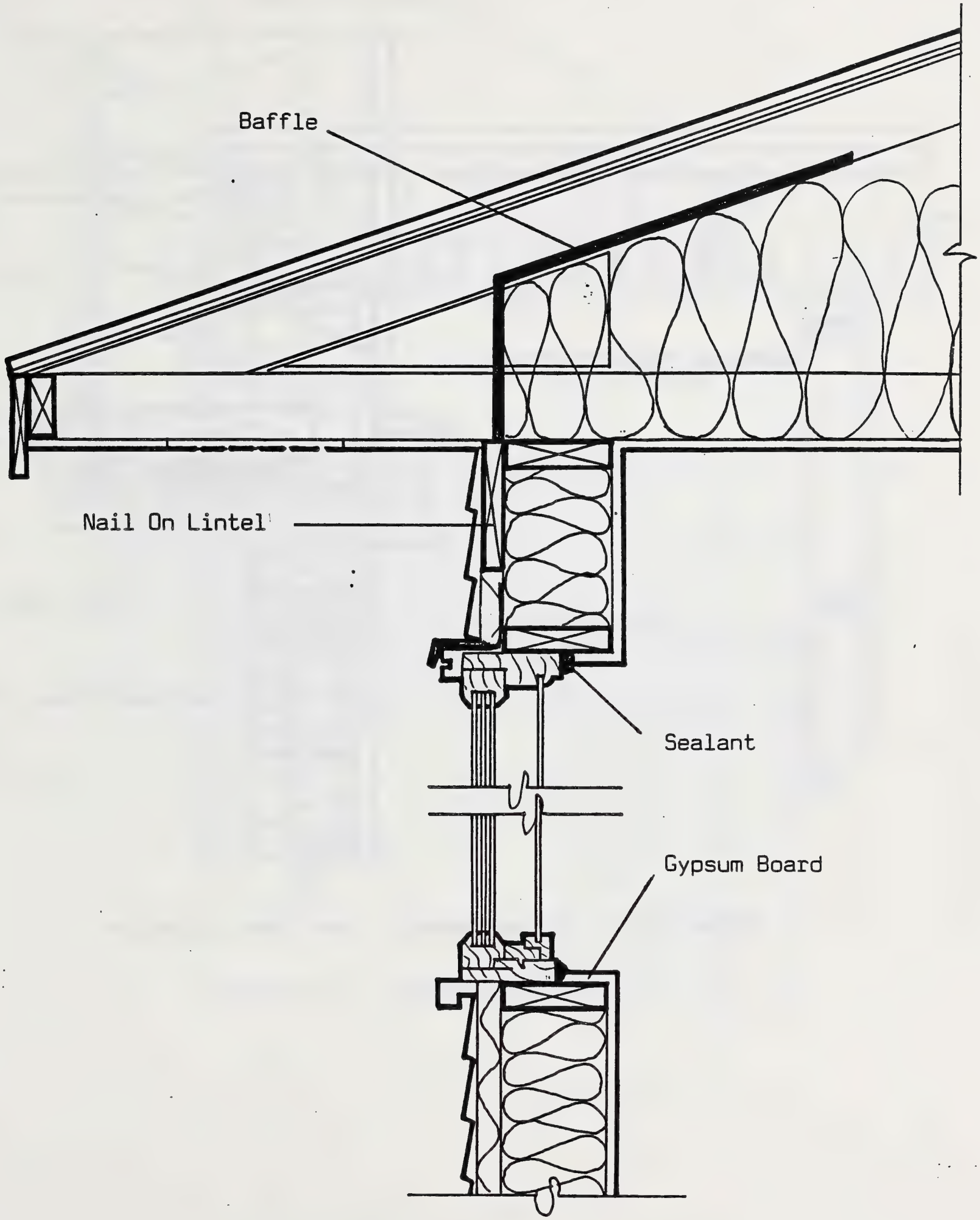


Figure D-13 : Window Detail Drywall Return

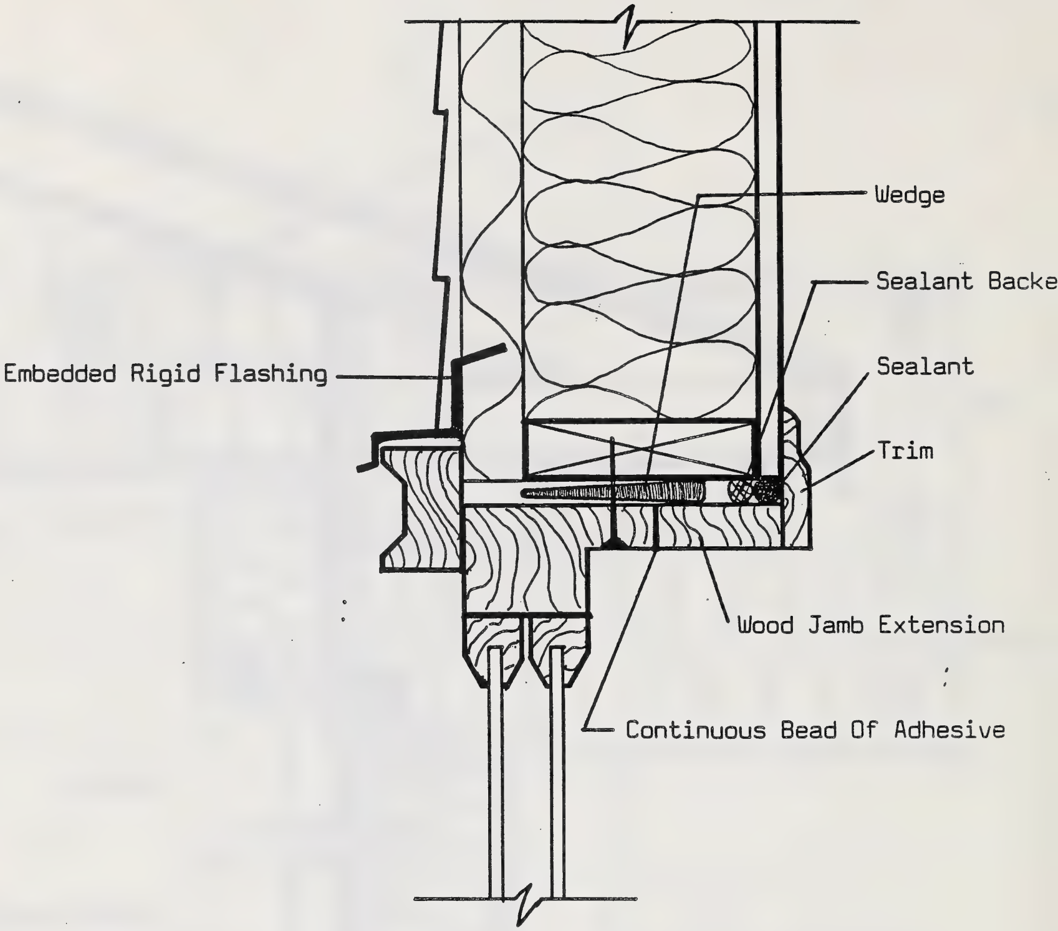


Figure D-14 : Window Detail - Wood Jamb Extension

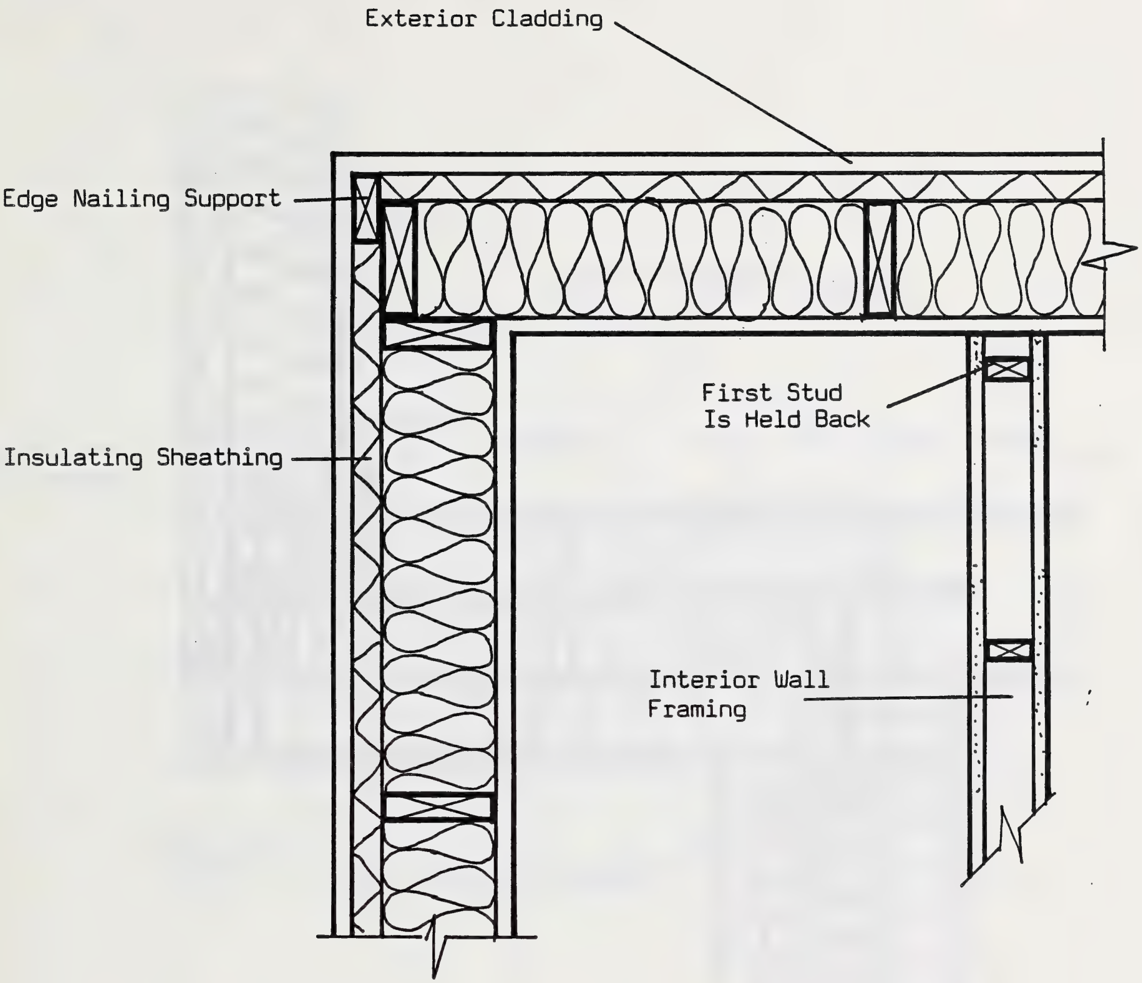


Figure D-15 : Exterior Corner

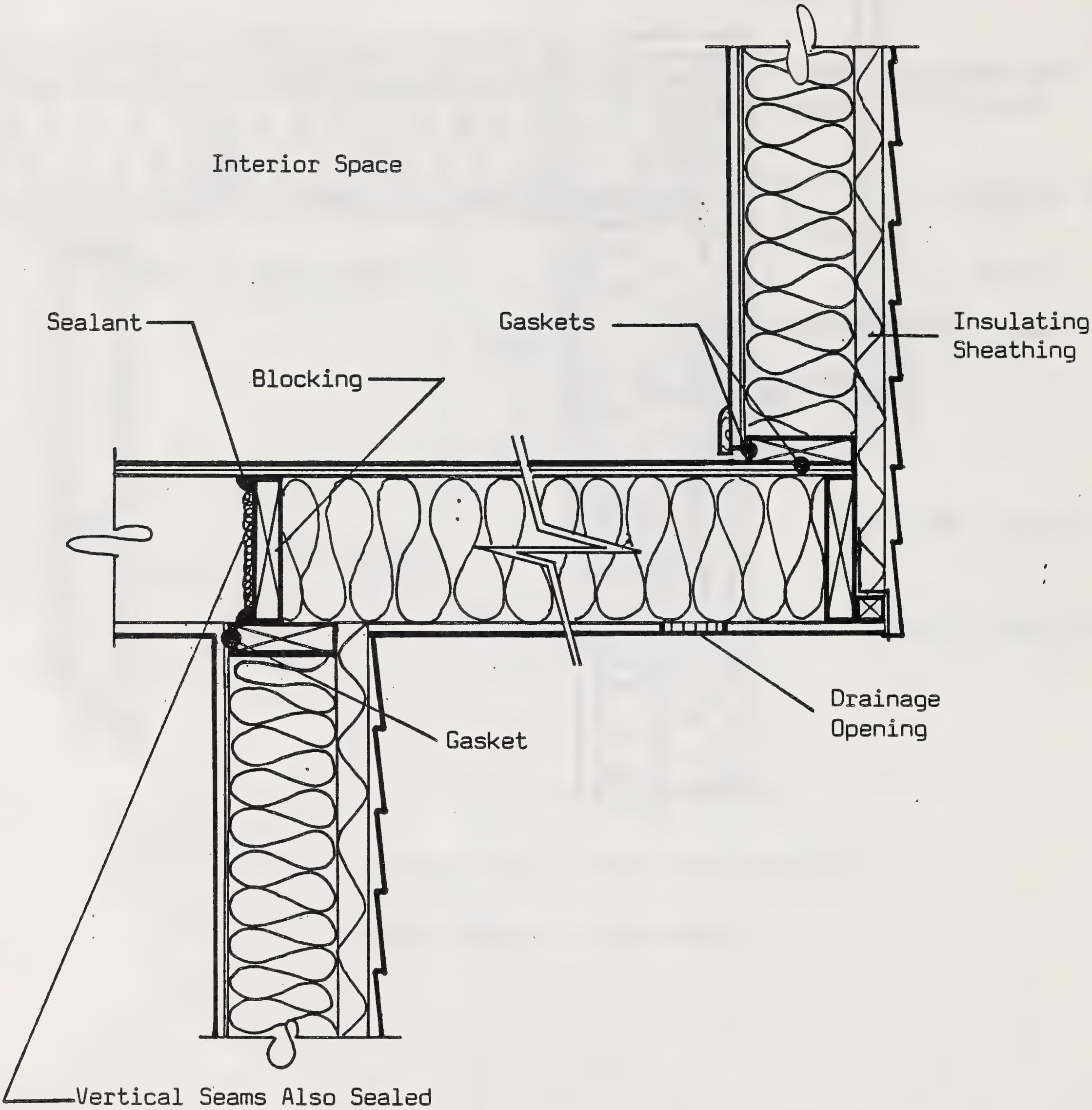


Figure D-16 : Cantilever Floor Intersecting Joists

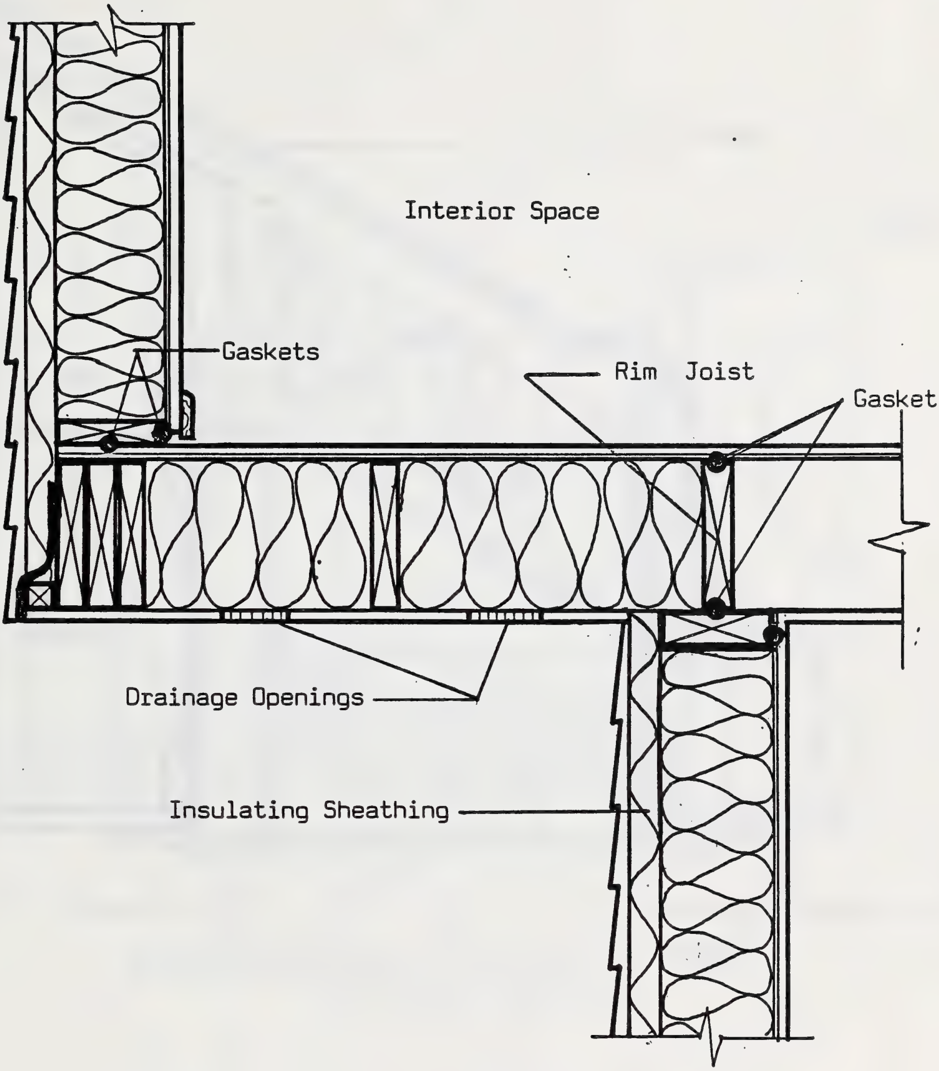


Figure D-17 : Cantilever Floor
Parallel Joists

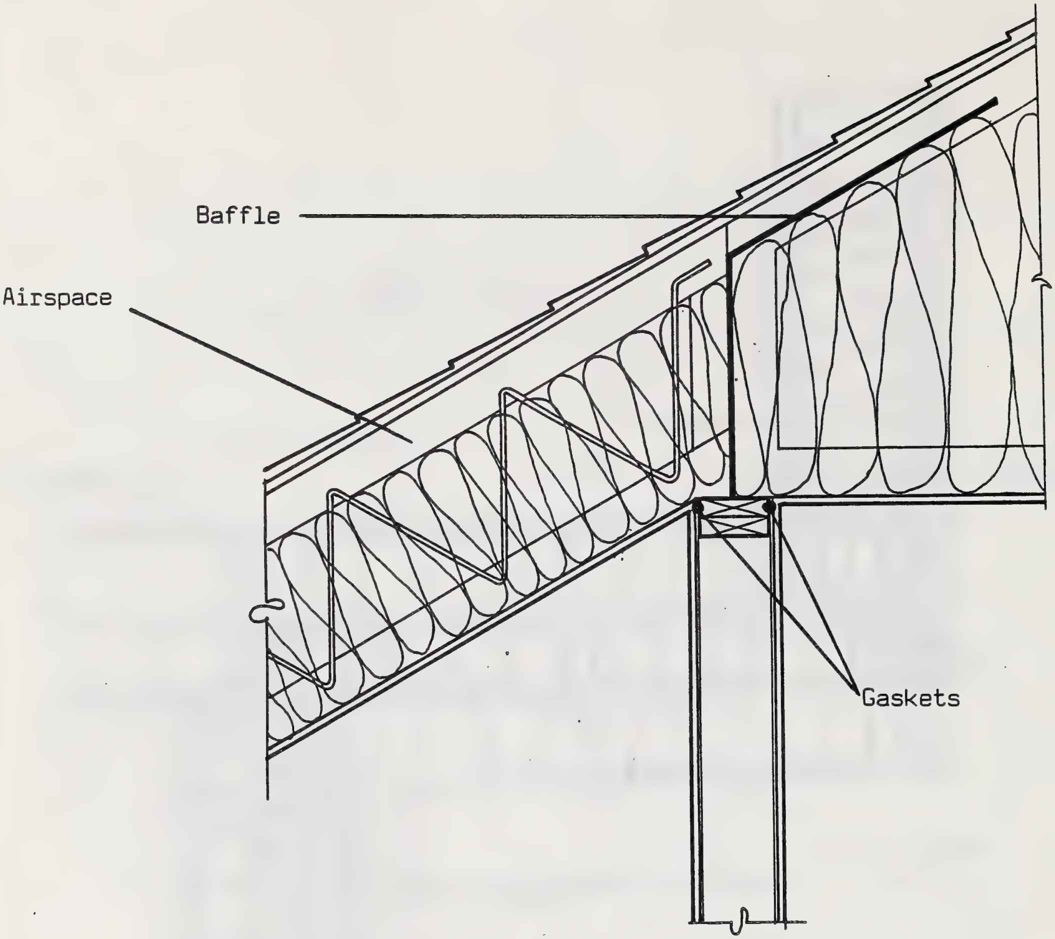


Figure D-18 Load Bearing Wall-Sloped Ceiling

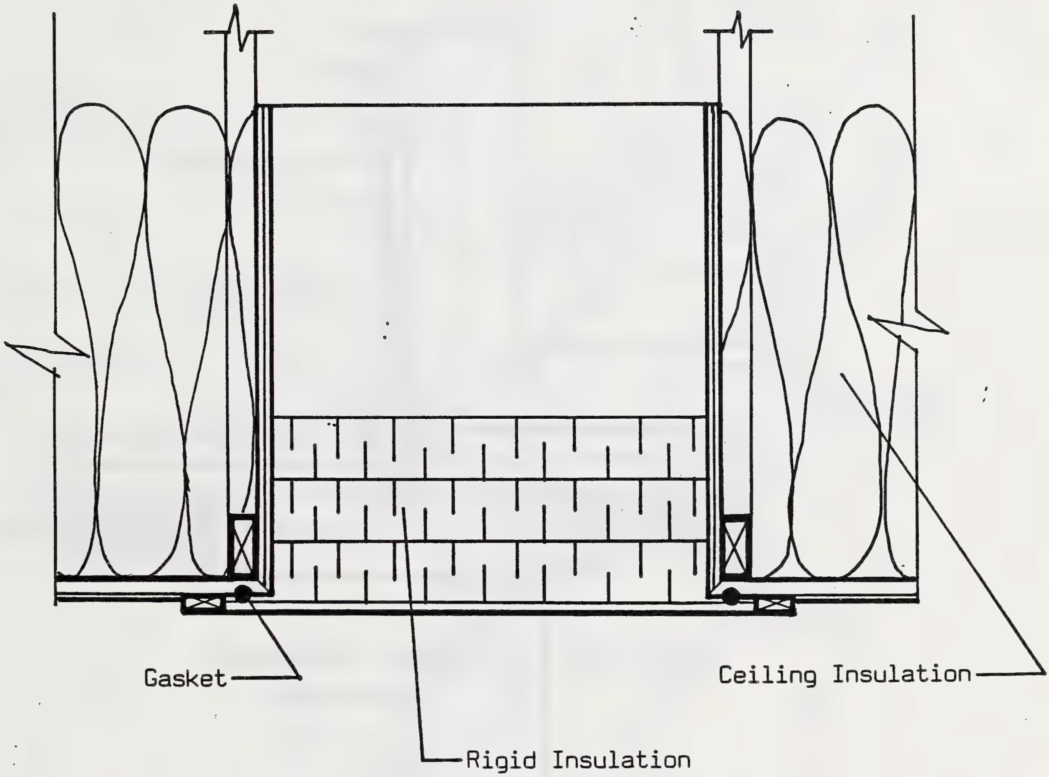


Figure D-19 : Attic Hatch

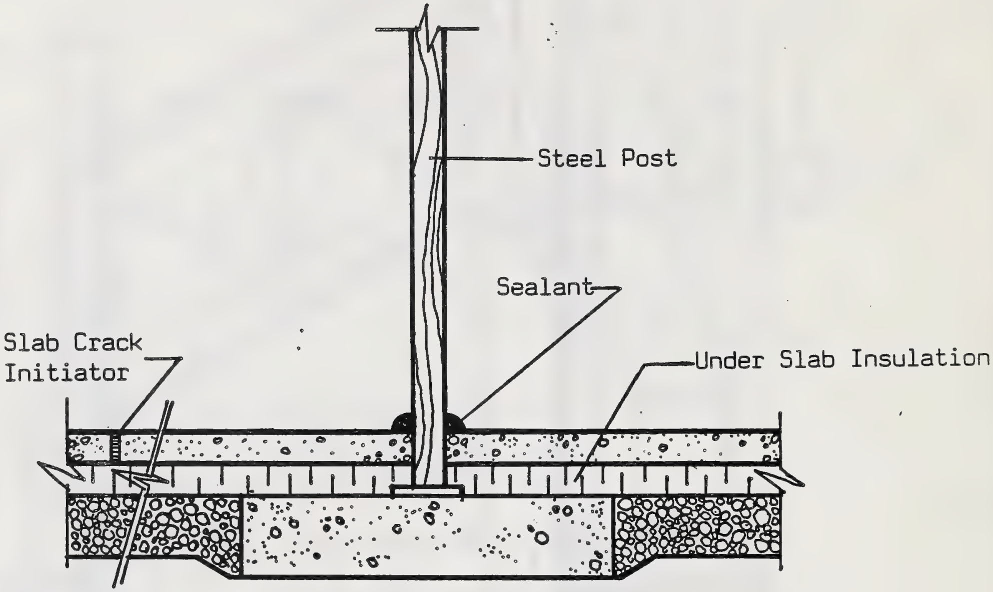


Figure D-20 : Post Detail In Basement

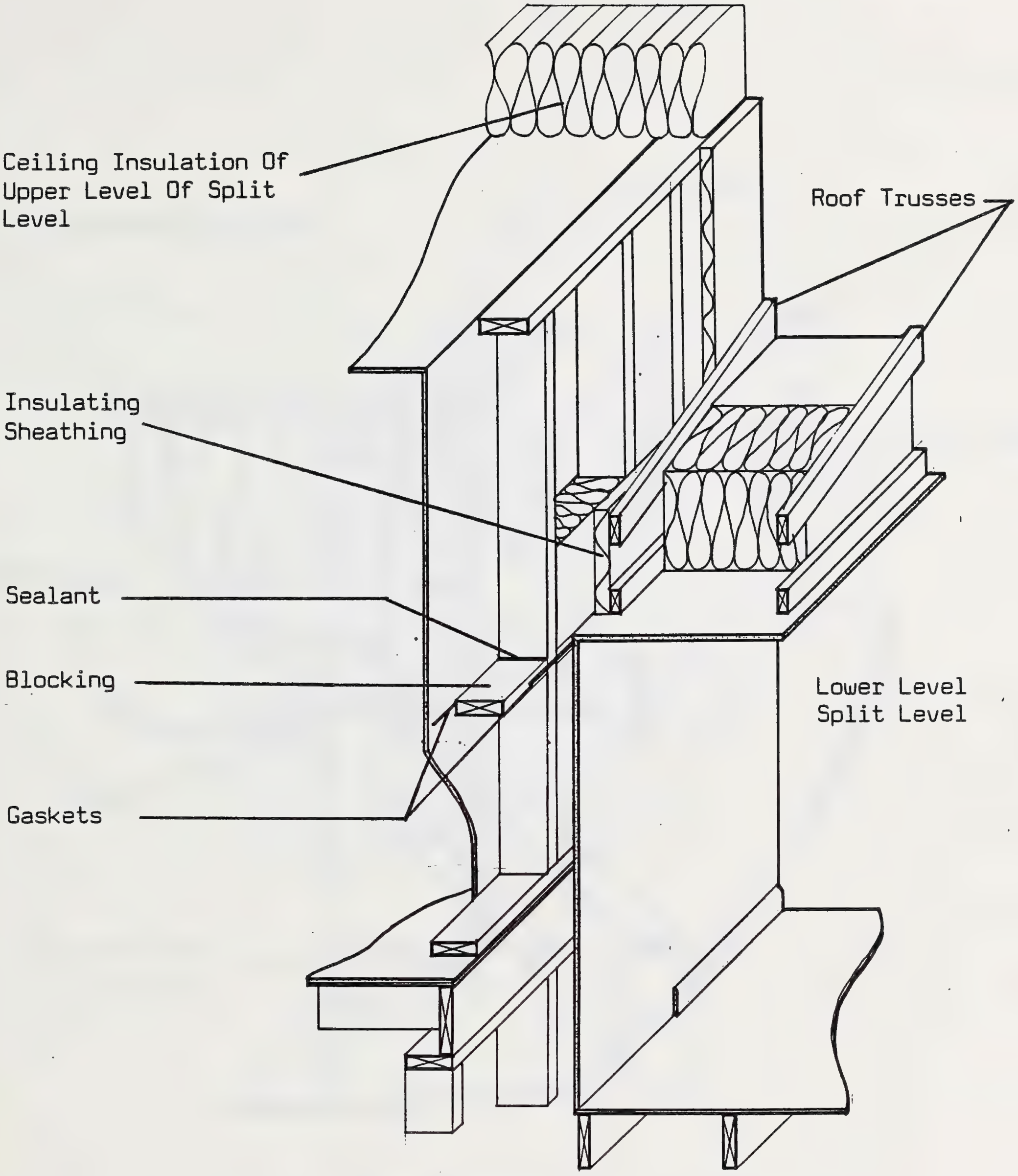


Figure D-21 Split Level Detail

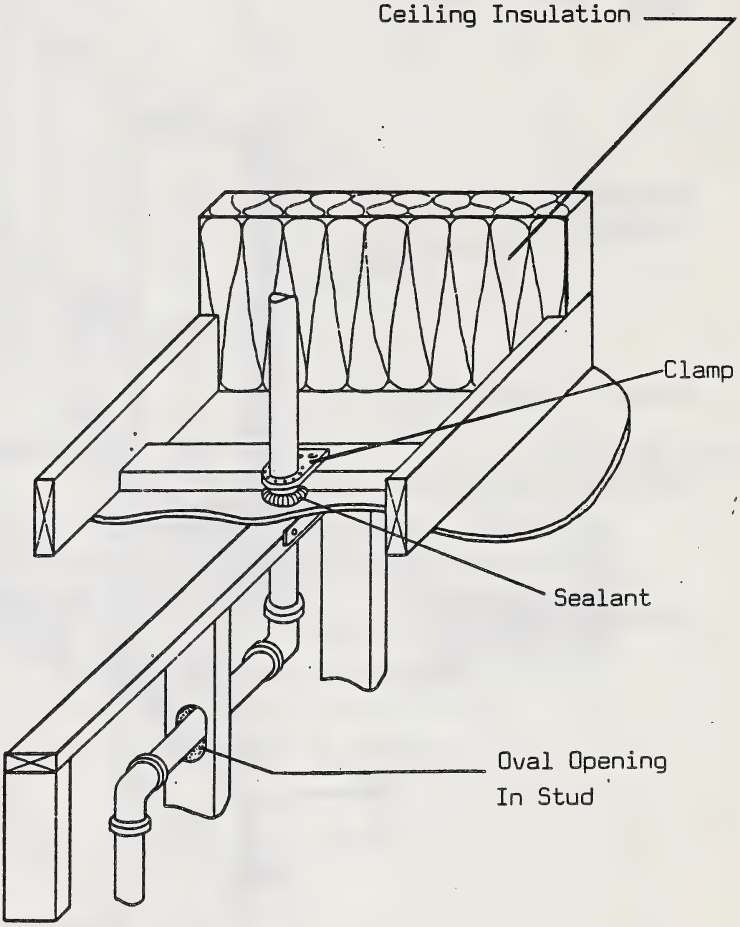


Figure D-22 : Plumbing Vent Pipe

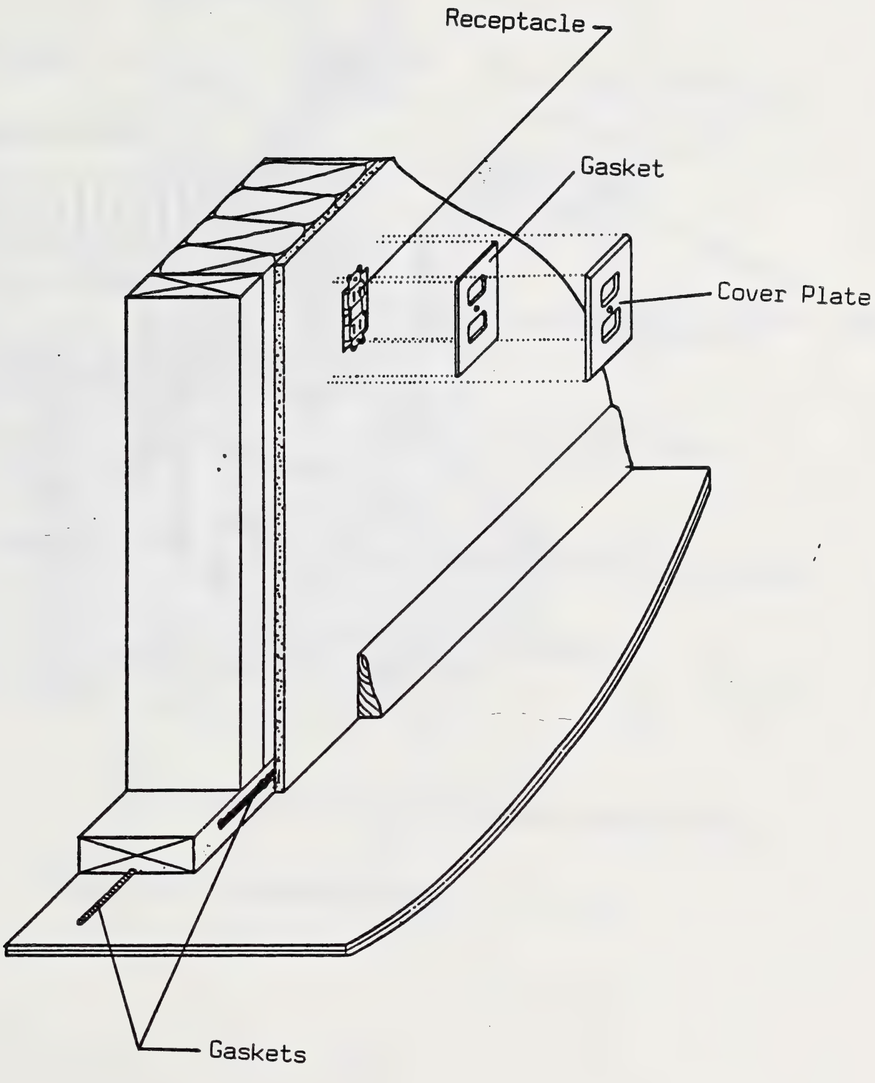


Figure D-23 : Electrical Outlet

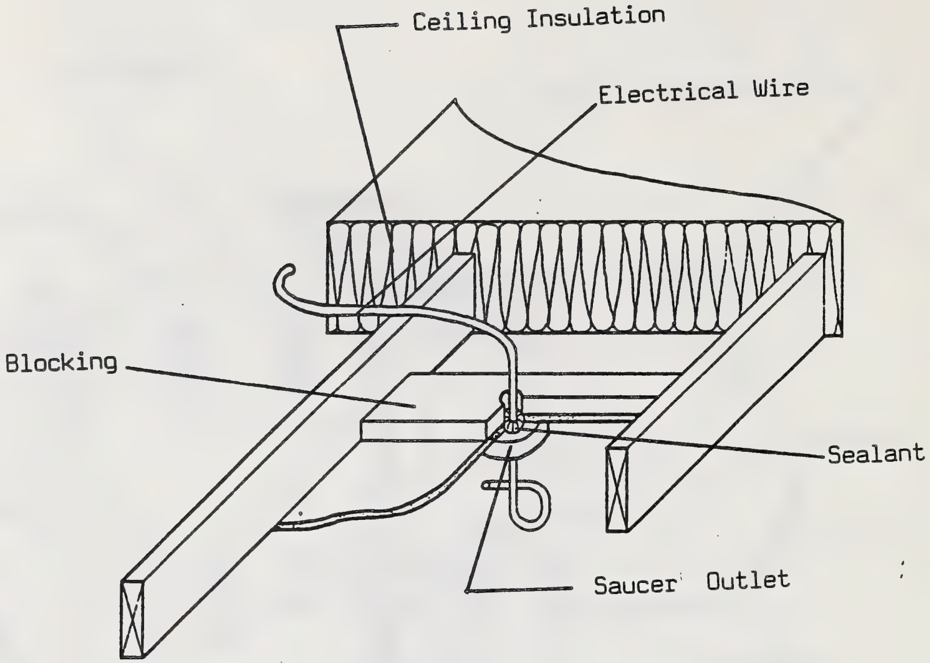


Figure D-24 : Ceiling Fixture

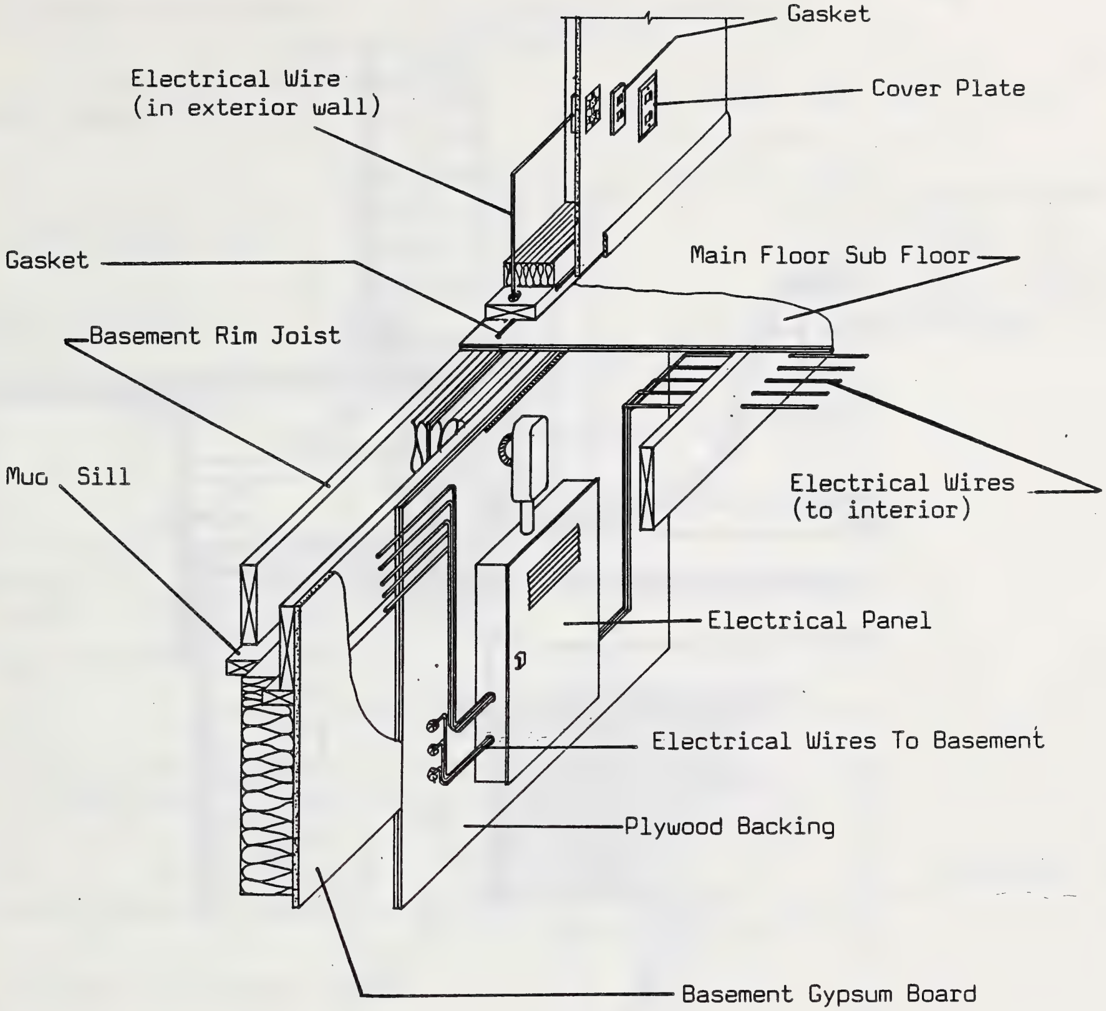


Figure D-25 : Electrical Panel

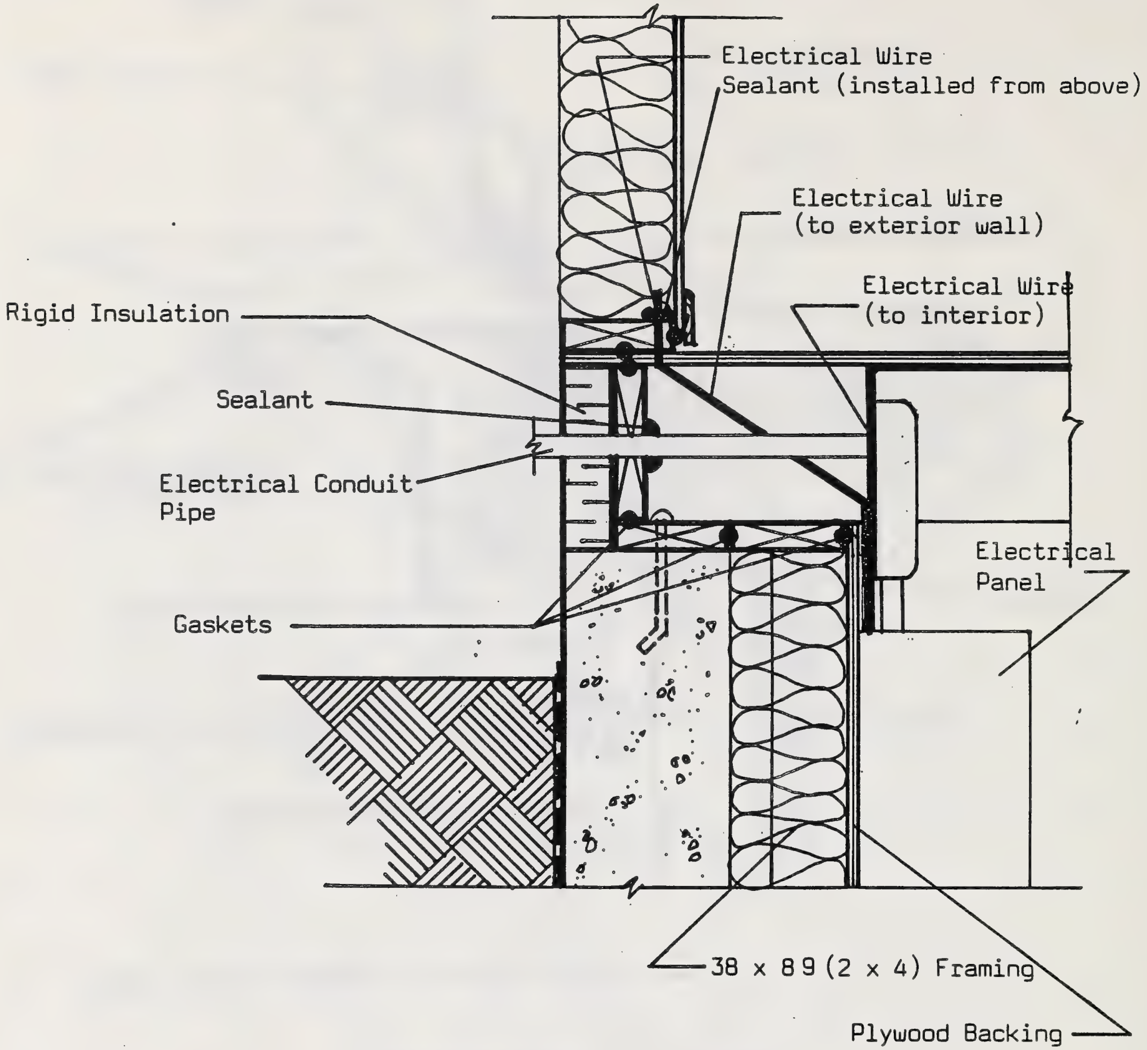


Figure D-26 : Electrical Panel

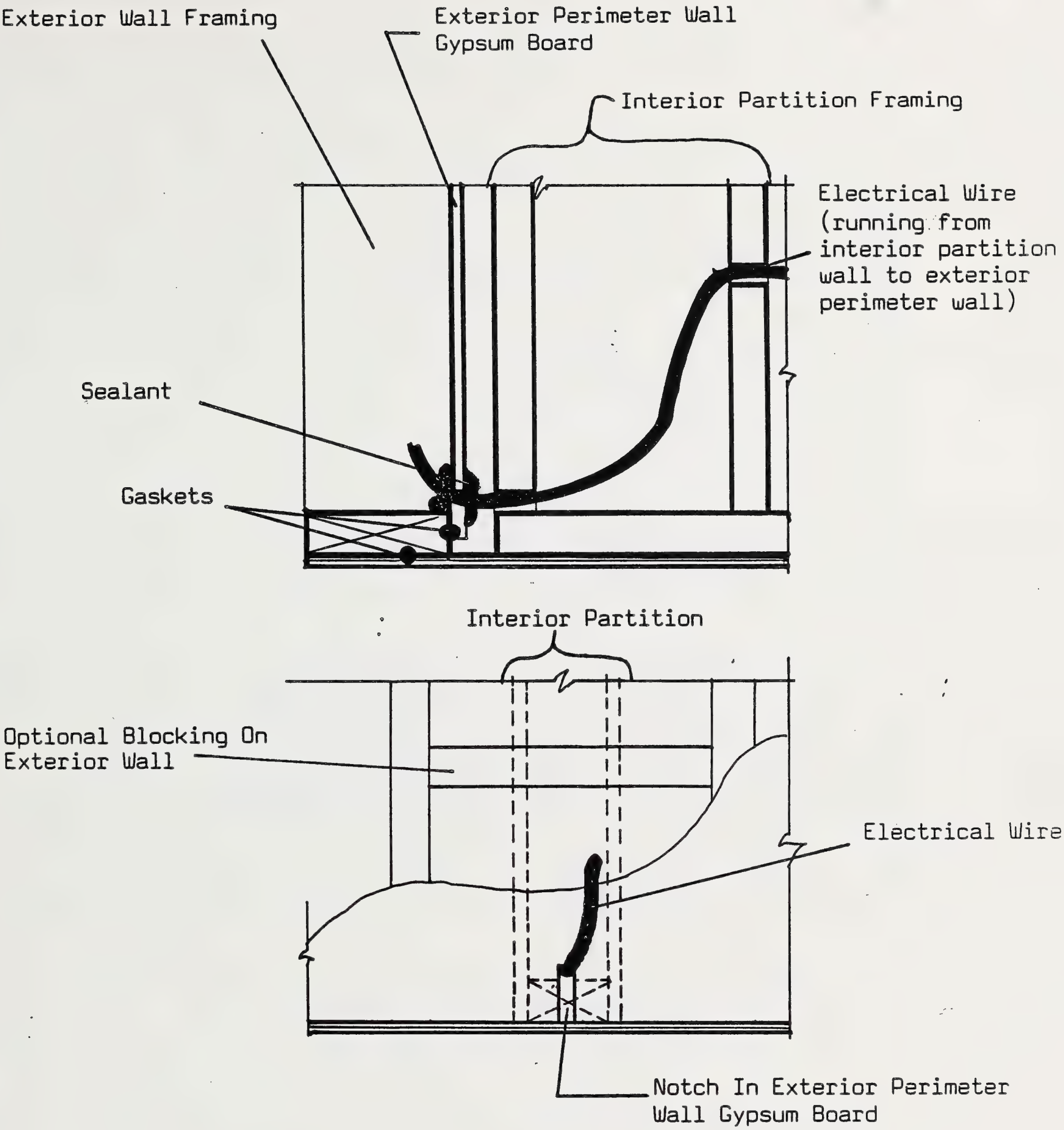

Exterior Wall Framing
Exterior Perimeter Wall Gypsum Board
Interior Partition Framing
Electrical Wire (running from interior partition wall to exterior perimeter wall)
Sealant
Gaskets
Interior Partition
Optional Blocking On Exterior Wall
Electrical Wire
Notch In Exterior Perimeter Wall Gypsum Board

Figure D-27 : Wiring Interior/Exterior Wall

APPENDIX E

APPENDIX E - TRADE INTERVIEWS FROM ALBERTA AIRTIGHT DRYWALL APPROACH DEMONSTRATION PROJECT

Interviews were conducted with the building trades after the completion of their work on the ADA houses. The following pages are a transcription of these interviews, edited for brevity.

1. Interview with Lewis Nakatsui, principal with Lincolnberg Development Corporation, covering the construction of the ADA houses.

Builder: Lincolnberg had been involved in low energy home building for 3.5 years when we built two houses under a provincial grant in the 1981 home parade. I believe that all homes should be built using the ADA technology. The objective is to create energy efficient housing, but achieve it with lower costs than what we have been able to achieve using the standard R-2000 procedure using polyethylene. For example, when we built the double wall house last year, my conclusion at the end of it was that unless someone specifically came and asked us to build a double wall house, and was willing to pay us for the effort, we would never ever build another one, or recommend to a client that he build a double wall house.

Monitoring Consultant: Are your comments directed specifically at the extra insulation, or the polyethylene/caulking, or both?

Builder: Both. The polyethylene creates a lot of extra work, and even when you do use the methods you are not entirely sure that you have a tight seal. I am also referring to the amount of insulation in the walls. The double wall system actually gives you more flexibility to add more and more insulation, but I am not convinced that it is economical to take the wall systems today much above R.S.I. 5.3 (R-30). I don't believe the double wall system that we used in our previous homes was economical, either in air-tightness or insulation value of the envelope.

Monitoring Consultant: How did you get in to the ADA house project?

Builder: In September 1982, I met Joe Lstiburek at the Vancouver HUDAC National Conference. After experiencing the problems inherent with sealing a house with polyethylene, I was really interested in this alternative method of creating air-tightness in a house. Joe's approach to the Alberta government to sponsor an experimental project has continued over the last year and a half and had culminated in the project that we are working on.

Monitoring Consultant: One of the big things on the ADA technology over the standard is its lack of polyethylene. There appears to still be some caulking done in certain areas. In the Bearspaw ADA house, you tried different systems to seal electrical outlets on exterior walls. Can you explain that?

Builder: We used three different approaches to the electrical outlets on the exterior walls. The majority of the electrical outlets have polyethylene hats enclosing the electrical boxes. We used a wooden backer behind the polyethylene hats in order to get a good seal between the hat and the drywall. We also experimented with two other electrical boxes, one was a traditional metal electrical box without any polyethylene hat, and a plastic box without any polyethylene hat. We found that metal electrical boxes without polyethylene hats were considerably leakier than the electrical outlets with the polyethylene hats behind them. We used foam gaskets on every electrical outlet but the electrical box without the polyethylene hat seemed to be leakier through the actual receptacle holes. In the outlets with the polyethylene hats, we caulked the polyethylene to the drywall. This was really easy. We put the wooden backers behind the hats, so that there was a firm surface behind the polyethylene and not just the insulation. Then the drywallers just applied a bead of acoustical sealant around the electrical outlet and applied the drywall. That was the only caulking that the drywall had to apply. In the ceiling, the superintendent (caulked a few wires penetrating the drywall).We tried to eliminate all of the ceiling outlets, however, we did not want to carry the program to the extent that it lowered the marketability, just because we did not want any penetrations in the ceiling. So we (installed) some flat pancake boxes over which the ceiling fixtures would fit. However, Joe Lstiburek feels that even eliminating all the polyethylene hats and using the foam gaskets under the cover plates would not have significantly affected the air-leakage test results. In other words, he felt that we could eliminate the polyethylene hats behind the exterior outlets and still have achieved a very tight house.

Monitoring Consultant: Do you feel that this technique is worth the effort?

Builder: Yes, I do. I think that the costs are reasonable for this approach. I think that as we get more experience, the costs will drop. Our goal is to achieve an energy efficient house at economical costs. I think that this method is going to let us do that. I feel this is the system that is going to allow us to really market energy efficiency.

I was never convinced after we successfully built the R-2000 house that we were going to be able to market its characteristics because it was just too expensive. After these ADA houses, I am really optimistic that we can do something with the system and market it to the public. However, I think our current economy will hold us back the most at this point, because I am not sure how many buyers are out there that would be willing to spend three or four thousand dollars more on energy efficient features, never mind twelve or fifteen thousand.

Monitoring Consultant: Were there problems particular to the application of the drywall approach in the Meadows house that were not evident in the other two homes?

Builder: There were some very unique details since this is the first time we built a split level. There were some intersections of concrete walls with framed walls that we didn't encounter in either of the other two houses. This is the first time that we weren't able to drywall the ceiling straight through.We had a cathedral ceiling running into a center support beam that we couldn't eliminate. We had to run the drywall to the beam, caulk it to the beam and then on the other side run the drywall again. In addition, in the Meadows house we used aluminum sliders as opposed to wood casement so we'll find out if aluminum sliders create any real problems for us in terms of air leakage. We are using a slightly different heating system in this house. We are planning to use a coil off of the hot water tank to heat the house so that it creates some problems but not with the air tightness approach. We are also using little air vents into each of the individual rooms in order to create fresh air and we're not using an air-to-air heat exchanger. We're using an exhaust system to exhaust stale air which is then going to creat a negative pressure in the house. This negative pressure is then going to draw fresh air into the individual rooms through these little valves.

Monitoring Consultant: Do you see this system working effectively? Would the fact that they have to be controlled manually by the homeowner and that they could possibly freeze up be reasons for concern?

Builder: The valves are easily controlled because they are just threaded plastic outlets that are meant to be placed on a Jacuzzi or whirlpool to control air into the system. There may be some freezing or condensation problems that we might have to contend with. It's to that end that basically, in terms of the penetration of the exterior shell, I've got it prearranged so that if I have to I can revert to an air-to-air heat exchanger with very little trouble. Realizing that it's the first time that anybody has tried this approach there are two considerations. The first is that because we don't have a heat exchanger are we really going to use significantly more fuel because instead of recovering heat we are just going to dump it. The second consideration is that there are going to be other extenuating circumstances like the freezing that is going to force us to modify our system or revert back to our old standards.

Monitoring Consultant: Can you suggest areas where you would still like to see improvements made?

Builder: There are certain problems we have to overcome such as the electrical for example. We started utilizing pancake boxes which under the strict interpretation of the code are not legal. They're only legal in terms of air volume for only one wire. I thought we had them convinced to let us use them with the fact that the drywall is actually separating it from anything above it. But they're allowing us to use only two or three of them. Now that sort of baffles me because if it's good enough for two or three why isn't it good enough for the whole house?

Monitoring Consultant: Overall, how much of a problem has it been to gain acceptance for the ADA technology from the various regulatory agencies?

Builder: Well it's the same old story. I'm always told by the people in the process of writing codes that they are there for guidelines and they're to be interpreted. But in reality, they are being interpreted by people that in many cases, I'm sorry to say, are not qualified. It's like you trying to understand a medical bulletin. Because you don't understand it fully you are forced to take it literally and that's what happens with regulations. If you don't understand the theory and don't even understand why it was written into the rulebook, your only choice is to interpret it literally, and that's what happens with regulations. So it doesn't matter if it's something as simple as the pancake boxes or something more complex - it always in the end,in the field gets interpreted literally.

Monitoring Consultant: Is there anything you would like to add?

Builder: The basic system works and we've demonstrated that with what I believe is a significant reduction in materials and labour to achieve the same things that the R 2000 houses using polyethylene film have been achieving in their houses. It still doesn't mean that with these lowered costs that we can convince the buying public to buy hundreds of these homes but it certainly has to be a step in the right direction.

2. Interview with Doug Bartlett, Framer

Framer: I am president and manager of Bartman Construction, Bartman Construction is involved in the ADA project as the framer on site. We have been involved with some of Lincolnberg's other special energy-conservation-type construction and have a good handle on what is required and the basic end results that are being looked for in energy conservation.

Monitoring Consultant: What training or background or education do you have in general, or in this area specifically?

Framer: I have a lot of job-site experience with different types of energy conservation construction. I was involved with my own company in building 2 x 6 wall construction and heavy vapour barrier construction, probably seven years ago which is actually quite some time before really anybody else in the area was involved in it. I have been talking with Lewis (Nakatsui) at Lincolnberg and working with him on a continuing basis ever since. I have attended classes at University and NAIT, upgrading courses that would be pertinent to the industry as a whole.

I am presently 30 years old. I have been involved in construction since the early 1970's. I worked my way up through a pre-fabricating house plant up to foreman of the plant, and after that, moved on to starting my own company in 1977. I have been a framer and carpenter ever since.

Monitoring Consultant: Does the ADA system make sense to you?

Framer: It makes sense to me very much.

Monitoring Consultant: Do you think it is worth the effort?

Framer: I think it is definitely worth the effort. I was involved with the construction of the R-2000 polyethylene home that Lincolnberg built last March. I personally got involved with a great deal of the joist bagging, and I was not doing that for very long before it occurred to me that there had to be a better way. "Not very long" means probably 4 hours after getting on job site and wrapping joists and realizing that this was a very labourious method of trying to seal a home up. At that point in time, it had seemed to me that there should be a better way to do it. I had discussed with Lewis (Nakatsui) that one should be able to make use of, as I felt, the wood framing members as a vapour barrier detail and eliminate the poly, so this system here definitely makes sense to me.

Monitoring Consultant: You mentioned that if you were going to do this again, it would take you less time. Since the work did take you more time, was it a combination of that because you were initially unfamiliar with what had to be done, or was it because it was not explained properly to you, or was it because it actually takes more time to do? Which of those would be the most important area to describe the increase in time?

Framer: First of all, we understood what we had to do. So it really was not the case of arriving on job site and trying to figure out how to do it. We knew how to do it. It was more a case of wanting to make sure we did it right the first time. Therefore one could assume that we probably put more effort into it to do it right than perhaps was required. Now if a person tends to over do it the first time, he can start to work backwards a little bit and improve efficiency. You have to get your technique correct first. Once you have got the technique, you can improve your efficiency. We discovered what the particular detail work which was required, and how one would deal with that probably next time around to speed it up a little bit.

In order to be considered truly efficient on one of these exterior wall systems, I think that one would have to work his way through three or four different houses. Once one had done that, you would have it down pat, assuming that the system was not changed in the meantime. Any data that one wanted to use after the third or fourth house, I consider would be probably very accurate in terms of labour.

Monitoring Consultant: Would you buy a house like this? Why?

Framer: Yes, I would. First of all, as I mentioned before, I happen to believe in energy conserving type construction. I was involved in it quite some time ago. I don't believe that the R-2000 poly method is really a viable alternative - I believe that this one is.

Monitoring Consultant: In general, do you think that this type of unusual framing will be too complicated to understand by other tradesmen if a lot of houses or all houses were built in this fashion?

Framer: No I don't. I feel that the construction techniques are basically quite simple. There is nothing beyond the comprehension of the average trades person. Maybe they won't understand the theory, but the techniques are within their grasp. Once again, I would like to compare this to the R-2000 poly home which I feel is a type of construction which is basically beyond the grasp and capabilities of a lot of trades people. They just would not understand what is required. There are too many areas for problems.

Monitoring Consultant: You mentioned that you were involved in other energy projects, specifically an R-2000 poly home. If you can comment in general, was this technique easier or more difficult, or in your opinion, better or worse?

Framer: The theory behind it, I understand, I think it makes sense. The ADA project as having just completed for Lincolnberg is new theory to myself, but it makes sense. I suppose I am fairly aware of what is going on in terms of energy conservation type construction. This is a very practical on-site approach in my opinion. I would use the ADA wall system to build a low energy home myself.

Monitoring Consultant: What did you like or not like about the other system, the polyethylene?

Framer: I don't think I can honestly say that I liked anything about it. What I disliked about it was the polyethylene sealing work required. It is tremendously involved. It becomes overly complicated when you start varying from a standard box type construction design of home. The more corners you have, the more complicated design of the home, the more complicated the R-2000 poly process becomes.

I think there are too many grey area or sealing areas that is often difficult to know exactly what has been sealed and what hasn't been sealed. You just don't know. You do your best but you still don't know.

Monitoring Consultant: Did the sealed polyethylene approach take you longer?

Framer: The sealed poly process took much longer. I think that the double-wall polyethylene R-2000 system probably took us roughly 5 times longer to construct.

Monitoring Consultant: How about a single wall with the caulked poly?

Framer: Of course, the single wall would be much less involved because you are only constructing half as many exterior walls. So you are going to cut your time there, but you are still involved with the joist bagging process. There is a lot of back work required on the exterior of the home. After the system has been erected, you have to go around on the outside and finish tying it together.

Monitoring Consultant: If you were to go to a rigid insulated sheathing that you can walk across, such as a rigid polystyrene such as Dow SM. Would that cut your time?

Framer: Let us just say that I would prefer to use the GlasClad System. You can actually misstep on top of this stuff, and it doesn't break, it bends, but it doesn't break. Whereas if you were to use the rigid insulation, one misstep and that is the end of the insulation. You would have to replace it. The GlasClad has give.

Monitoring Consultant: Is there anything at all that you would like to add?

Framer: One thing that I really did not deal with was the fact that this type of construction, of course, involves the construction of the shell - the shell being the exterior walls and the insulation in the roof; the interior partitions being framed after the shell has been drywalled and taped. This adds a little bit of time, in so much as, when you are lifting the trusses up on the roof, you don't have anything in the centre of the home to walk on. There is nothing there to act as scaffolding for the roof erection itself.

We found that we had to build a centre scaffolding down the centre of the home in order to have something to walk on. This is one thing you run across that is required that wouldn't be in a normal home. In a normal home, the partitions are there. You have got something to walk on. In this particular instance I figured that it was costing us approximately $75. extra, about 5 cents per square foot (54 c/m2).

The actual construction of the partitions afterwards was no problem at all. All we did was go to a 1x4 cap plate, rather than a 2x4 cap plate. Of course, we had our backings correctly positioned in the walls and ceilings as required. The installation and nailing down of these walls was no problem. It went well.

Monitoring Consultant: Did you have any contact with any of the other trades in the construction of this house?

Framer: I had a reasonable amount of contact with them prior to and during construction. All of the other trades involved in this, like myself, have been involved on a continuing basis with Lincolnberg. They understand what Lincolnberg is trying to achieve, they know that it is not typical in terms of what they have been doing day after day. They are willing to adapt; they have a good attitude about it; they are eager to do well on it. They are good to work with. Everybody has been good to work with. Initial attitude or interest in working on this is fairly important. I think if the interest isn't there, the technique will never be perfected, and the job will never be done correctly.

Monitoring Consultant: The design of the River Ridge was more complex than the Bearspaw home. Did this make the application of this particular air barrier technique more complex also?

Framer: Yes, this was a more complex home to frame than the Bearspaw home, it would have been had it been an ADA house or not. The main floor itself was not much of a problem. Where we ran into more complex detail work was on the second floor joisting where some of the joisting overhangs into the garage and on the stairwell because of the fact that we had to put in an angled wall to get the required headroom. It was not a problem to seal but a problem to visualize beforehand so that one could seal it correctly.

Monitoring Consultant: The design of the River Ridge is such that there are unheated areas jutting into heated areas, that is, this is not simply a box design but there are in fact irregular wall lines. First of all, could you identify these areas for me?

Framer: On the garage (SW corner of the house) there is a strange detail in that the floor line below is essentially a square corner with the floor above following this square corner, but the wall above is jogged in - it does't follow that corner. The corner falls 4 ft. short in both directions so it comes in and forms an inside corner. In that area, we made use of the 5/8 in subfloor as the air barrier. We caulked any joints in that subfloor that was acting as the air barrier. You then have to make use of the floor joist in order to span the sealed floor joist rim back to the wall line above. This is similar to the way the joist are caulked to the subfloor in the basement.

In the living room there is a bay window that just has the trusses above. The bay window was basically a very easy detail to do because in this instance (unlike the corner just mentioned) we were able to place the gaskets on the bottom side of the joists above which follow the wall line above. This made it easy to keep the air barrier continuous.

Monitoring Consultant: Can you suggest further improvements in the use of gaskets?

Framer: Once a person has time to stop and catch his breath and think about it he might refine the system a little bit more, but right now, we aren't having any field application problems so I'm satisfied that the gasket techniques are basically correct.

Monitoring Consultant: Having framed three on these ADA homes now, what are your general comments?

Framer: We found that the more experienced you get at it, the smarter you get at it and in terms of something that seemed awfully complex the first time you run into it, the second time you run into it there is an easy way around it. A good example was that stairwell in the River Ridge home. When we did it the first time, there was nothing wrong with it but in retrospect, it was the hard way of doing it. It's something you just have to get in there and experience. You really cannot teach someone that. Also, on the jobsite there's not just one man that understands it, but every man understands it, so every man is always suggesting this and suggesting that. It really makes a difference because one man cannot think of everything.

Monitoring Consultant: As you begin building more of these homes and more people become involved, how will their training be handled?

Framer: As I see it, it's a three-step procedure. Number one, it involves a site visit to get an overall view. Number two, it involves a slide presentation some of it more detailed. This is followed by a small seminar where all the people involved have to be there.

Monitoring Consultant: Do you see the airtight drywall approach as a system that could be adopted in a larger way by tract builders?

Framer: From what I've seen of it so far, and with our experience in being able to reduce construction time and problems, I'm more so of a believer than when I talked with you last time. Now assuming the theory behind it is correct and it withstands the demands of time then yes, it will catch on. I know I would build a house this way if I were building my own.

3. Interview with John Bakker, electrician for K.Jay Electric, covering the time spent on the ADA Projects.

Electrician: I have been in the trade for about 15 years. I am a Master Electrician, having gone through the apprenticeship program, and have been a journeyman for 3 years.

Monitoring Consultant: How did your work on this home differ from the work you would normally have done on a home?

Electrician: There were various differences. Initially, when we wire a house, we go there in one trip and we wire the whole thing. On this particular home, we had to go twice. First we went and wired the exterior walls and ceiling area. After that was completed, it was boarded. Then they framed the interior walls, and we went back and wired that.

Monitoring Consultant: Except for the fact that there were two trips, was there anything unusual or extra about the wiring?

Electrician: Yes, usually when you run your circuits, you run them over top through the attic space. You are on the same floor as your wiring. Now, (with the ADA house, when wiring the interior walls,)all the wiring (to and from the walls) had to go underneath, into the basement, (and remain within the air barrier.)Also, when we did the exterior walls (on the ADA house), we ran our circuits continually all the way around the outside walls, whereas we would usually catch the circuits in the area. So it involved a bit more wiring. But most of the (extra) time would be spent on the interior walls, because you would have to drop the wire, run downstairs, and you would drill back up.

I would say that approximately four hours extra were spent in wiring the house, including the driving time for the second trip.

Monitoring Consultant: Was there anything about the design of the house, that made some parts of the wiring easier, or was there only additional work?

Electrician: There was only additional work.

Monitoring Consultant: Do you think that it is worth the effort?

Electrician: I think that if it saves you the cost. With any of these new concepts they get,(the trade that gets screwed up worst is us). It doesn't make much difference with the plumbing, or heating, but we have got to go through all these walls with all our wires. We spend more time in the house running around through the walls.

Monitoring Consultant: Can you suggest any improvements?

Electrician: If they went to scissor, open trusses in the basement, that would make it a lot easier (to run the wires through the interior partitions). That would save a lot of time.

Monitoring Consultant: If you were to do it again, do you think it would take less time?

Electrician: I don't think you would save much time doing it again. I don't think it was any more difficult, it is just that it takes more time, because there is more running around.

Monitoring Consultant: Would you buy a house like that?

Electrician: Yes, I think that if I built a new house, I would go to a sort of an energy home, and this is the most economical way I have seen of doing it.

Monitoring Consultant: Does anything bother you about what you did or what you saw?

Electrician: Well, one thing I did, that I know I won't do again, is where I drilled the holes down on the outside (wall), I know I hit the centre of that gasket sometimes - next time, I will make sure that I stay towards the exterior of the wall.

Monitoring Consultant: Do you wish to add anything?

Electrician: One thing that was fairly difficult about the ADA house, was to locate exactly where the lights were and where we drop our switches down from the top. You come into this place, and there are no measurements exactly to the location of the lights. So you have to sit on this plan and scale it all out, in order to figure out exactly where your lights go. Sometimes, you are measuring 20 feet (6 M) in order to centre a light. You have got to get it exact. Whereas usually when the walls are framed, you can easily measure 6 feet (1800 MM) from this (interior) wall or that. Now you are measuring everything from exterior walls. So that was a lot more screwing around to get those lights and switches exact.

Monitoring Consultant: Were measurements properly indicated on the plans from outside walls?

Electrician: Yes, but you still have to measure on-site to locate the centre of the room, or from one wall. The ceiling lights that we had, we ran the wires through the attic space and then down the wall. But we had to know exactly where we were coming down that wall. It ended up working out really well.

Monitoring Consultant: Whereas the Bearspaw home was a single storey design, the River Ridge house is a 2-storey unit. How did your work on the 2-storey home differ from what you would have done normally?

Electrician: It was basically the same.

Monitoring Consultant: The River Ridge home is also a more complex design. How did this affect the work you had to do?

Electrician: Actually the 2-storey worked out a little easier because we didn't end up with as much stuff on the outside walls - it was basically in the middle.

Monitoring Consultant: How many trips did you have to make to this house and what has been the extra time involved?

Electrician: We made one extra trip there to do the outside walls and time, I'm sure it was probably an extra 4 hours.

Monitoring Consultant: What can this extra time be attributed to, and do you think it could be reduced further?

Electician: Well just the extra time to re-route the wires - you couldn't just run around the outside walls. It was the same as what happened on the Bearspaw house. You can't get rid of that time, I don't think so.

Monitoring Consultant: You spoke about the Bearspaw home and the difficulty in locating exactly where the lighting should go and where the wiring for the switches should be dropped down. Were changes made to the Ridge River house to improve this situation for you?

Electrician: There were no problems on the main floor because the walls were in an upstairs, it was small so it was not a problem to deal with. They (the framers) indicated on the ceiling truss where to drop the wires for the switches.

4. Interview with Andy Jensen,Drywaller

Drywaller: I have been putting drywall up for about 16 years, and did the boarding on the Bearspaw ADA house. The time it took me was shorter than normal by a couple of hours.

Monitoring Consultant: What was unusual about the work that you did on the ADA house? What did you have to do that you do not normally do?

Drywaller: For instance, normally, we have to cut out all the walls for the interior partitions. But with this way, we could put the whole ceiling up, and everything was closed off and sealed. The foreman put the gasket up on the bottom plate. At first the gasket was too thick, so it had to be taken off and replaced. But all I did was board it in a normal fashion. It made it easier for us to work because we did not have the interior partitions.

Monitoring Consultant: Do you know why you did what you did on the house?

Drywaller: Yes, it was to seal any air from getting into the house or the walls.

Monitoring Consultant: Does the savings in time by going with the bigger sheets on the ceiling, is that more of a savings than the aggravation of having to go back twice. How do you feel about that?

Drywaller: Having the ceiling clear of any interior partitions makes the house easier, but then you have to go back to the house a second time. A smaller house you can finish in one day, but with the ADA method, you have to go back later to finish it. With a bigger house, you have to go back twice anyway, so the ADA method gives you a saving by clear sheathing the ceiling of the upper floor.

Monitoring Consultant: If you are going to do this again, would it take you any less time? Could you do it faster the second time?

Drywaller: Well, we probably could because we had to wait a couple of hours that day when they were taking that old gasket off the baseboard, and putting the different stuff on. Yes, a couple of hours quicker for the next house.

Monitoring Consultant: Would you buy a house built using the ADA method?

Drywaller: Oh, I certainly would.

Monitoring Consultant: Do you like not having to put the polyethylene up and sealing it like that?

Drywaller: Oh yes, but I do not know how it is for the future yet, but I believe that it is the right idea.

Monitoring Consultant: Do you think if a lot of houses were built in the same way that you were doing it, would it be too complicated for other drywallers or other tradesmen?

Drywaller: No, it is very simple.

Monitoring Consultant: Were you involved in any other energy-efficient projects such as the other Lincolnberg R-2000 home?

Drywaller: Yes, I was

Monitoring Consultant: Has this been easier than that home, or was the other home more difficult to work with?

Drywaller: Well, this house was easier to work with.

Monitoring Consultant: Did you have any problem with the amount of fasteners or screws that you had to put at the bottom of the wall to seal it?

Drywaller: No, not after we got the second gasket on. The first gasket was too thick. The second gasket worked fine.

Monitoring Consultant: We want to talk to you about drywalling the outside walls of the basement. How long did this work take you to do?

Drywaller: It probably took five hours to do the outside basement walls. It was longer than it normally would take because we had to cut all the joists out. Probably two hours more for two people. We lifted the drywall up (against the joists) and made marks on it (then cut out the marks). That was the fastest way to do it. We had to do it this way to get the house air-tight.

It can't be speeded up all that much because we had to be very exact. Once we had the marks where the joists were, we had a big T-square to measure exactly straight. One guy would lift the sheet up, and the other guy would make marks on the drywall. That would get it fairly exact. It was definitely a two-man operation, like a normal house.

Monitoring Consultant: With all of the time you saved drywalling the main floor because you were able to sheath the ceiling straight through, did you lose all of that time in this basement operation?

Monitoring Consultant: How much time did you save by putting the drywall straight through in the ceiling?

Drywaller: Probably a couple of hours, I think; we had only 3000 (square) feet (280 M2) to put up and then we were finished.

5. Interview with Stan Hest drywaller with Crystal Drywall on the work done on the Meadows Show home.

Monitoring Consultant: How did the work on this house differ from the work you would have done normally?

Drywaller: Well, one thing, the basement exterior walls were drywalled whereas a normal house they wouldn't be. The drywall continued - on your exterior walls to the underside of the subfloor. I think that's a good point in itself even without the other things they were trying to achieve - to get it sealed all around. I think that's where most of your energy is lost.

Monitoring Consultant: Was it a difficult task to notch the drywall to fit between the joist?

Drywaller: The notching was slow going, it's something that you take step by step and go ahead and get it done. It's quite a bit of extra cutting but we actually screwed the drywall in place than marked our studs, squared them off, cut them out and it didn't really go too bad.

Monitoring Consultant: What was the extra time in doing that?

Drywaller: For that house it took two to three hours longer.

Monitoring Consultant: How was the work different in the rest of the house?

Drywaller: As far as the boarding itself there was a gasket at the bottom that you had to be careful with so you didn't knock it out of place with your drywall. You had to be kind of careful too that you didn't drive your nails too far so they didn't go through the paper - then they wouldn't hold anything. Other than that, we had to return all the windows in behind the window frame a quarter of an inch. That's not done on a normal house.

Monitoring Consultant: Is there extra time involved with the taping?

Drywaller: There was a little bit of extra time. He did have to make one extra trip to seal the areas where the interior partitions come. For the Meadows house which is a big one, there was about 9000 feet of board, he would spend half a day at the most coming and going. In a house that size once you get set up it doesn't take long to run an extra hundred feet of tape.

Monitoring Consultant: Were there extra trips involved for the boarder also?

Drywaller: There was one extra trip for the interior walls. In a normal house we have to go back and insulate it once the basement floor has been poured and the electrical and plumbing goes in. So extra trips are more so with the taper. If we can coordinate so the insulating can be done and we can go ahead and board right away then there is no real hardship.

Monitoring Consultant: The extra time you have mentioned for drywalling and taping - do you think this could be reduced on subsequent houses built this way?

Drywaller: It could maybe be cut down 20 - 25 percent.

6. Interview with Roger St. Hilaire, Insulator

Insulator: I have a Grade 9 education, and have done insulation work for about three years, having learned it on the job. I installed the glass fiber batt insulation in the main floor walls on the Bearspaw house. It took about six hours to complete the job. The house has a floor area of about 1500 square feet (140 M2).

Monitoring Consultant: Was there anything unusual in the work that you had to do on that house as compared to the work that you normally have to do?

Insulator: Not really, except that you did not have to do any caulking. The rest was standard. Compared to the standard house the ADA was easier because we did not have to do any caulking, or put up any polyethylene. We spent about three hours less time because of no caulking. Normally, we have to do a lot of caulking as part of the insulating process.

Monitoring Consultant: Do you think that with the gasket it will seal up the house as tight as what you can do with polyethylene and caulking?

Insulator: The gasket will seal it better - the caulking will shrink after five years, or crack.

Monitoring Consultant: Do you think that putting on the gasket is too complicated to understand by other tradesmen if a lot of houses were built like that, or do you think that,that is a fairly simple technology?

Insulator: I think that that is simple.

7. Interview with Wayne Fedorak, Construction Superintendent

Construction Superintendent: Basically, I have been in construction ever since I left high school, in different aspects from framing to cribbing and finishing. I have been around construction for about 12 years. I am 31 years old.

Monitoring Consultant: What were the unusual things that you had to do on this project, compared to what you normally have to go through?

Construction Superintendent: It starts right with that foam rope; to the idea of putting up the exterior walls and drywalling first; the interior walls after; providing proper blocking for the walls that go in after; the ways of sealing up things; thinking things over, like the joist layout in the basement so that it matches up with the walls that we are going to put in; the fireplace required a little more care taken there. I guess that it is just watching for the fine details and making sure that everything is square, and that whatever we do is able to be sealed up properly.

Monitoring Consultant: This caused you to spend more time over the time that you spent normally. Did any of the details of the approach make it any easier for you to carry out some aspects of your work?

Construction Superintendent: Up to this stage, not really. I just had to watch a little more. There was a few details that we had to work out. If you did a few of them and used the same trades and they are more aware of what is involved, it would be easier.

Monitoring Consultant: Yes. Can you suggest any improvements as far as you are concerned, that you saw with the house from the very beginning? Are there any areas that you would like to see improved?

Construction Superintendent: Actually, the only thing that I did not like (to work with) is the Glasclad. It is a lot more trouble. It shows bulges and making backing for all the trim boards, maybe because this is a stucco house. If it was siding, it would be a lot easier. Stucco/Glasclad is a tough one. You can even see it bowed. I think we are going to have a little problem there. I have already talked to (the stucco appliers) about having a try to screed it out.

Monitoring Consultant: What other problem areas do you see that need more work? How arethe trades reacting? Co-ordination seems to be more complicated.

Construction Superintendent: Some of the trades have to make one or two trips more than normally - the plumbers, the electricians, the framers, the drywallers. That is basically it for the trouble. We try to take care and figure out what would be potential problems, like on the ceiling, plugs and the walls. We had a little trouble with that foam rope which was too thick for the drywall (on the bottom plate), and we had to use foam tape. We had to take the rope off.

Monitoring Consultant: If you were going to do this again, do you think it would take less time?

Construction Superintendent: Yes, it would. There were delays in scheduling because of the mortgage inspection and with trying to work out some of the details, such as how to seal up some of the joists. We had a lot more meetings with the plumber and the electrician, so they understood where their ground-works had to go. Putting up all the proper backings in the ceiling for the wires to go through the pipes, and we had to get the plumbers in the first time just to put their vents through the roof so we could do the roofing.

Monitoring Consultant: So you had to have the electrician talk to the framer, so that he located the backing for the ceiling lights.

Construction Superintendent: Yes, basically where the walls were measured out and snapped out on the ceiling as to where the walls would be and the blocking was put in the right places.

Monitoring Consultant: I understand that you put the gasket on for the drywall at the bottom of the wall. Do you think that that is a job for the drywaller to do? Who do you think should do that?

Construction Superintendent: I think that the gaskets under the plates definitely has to be the framers. The gaskets along the walls (next to the drywall) and any interior stuff, I think should either be the insulator's responsibility or possibly somebody who works for Lincolnberg. It could be the drywallers if they knew exactly what was involved, and it was double-checked.

Monitoring Consultant: Insulators normally insulate and put up the polyethylene and caulk it. Do you think there was much work saved by the insulators? How much time do you think was saved?

Construction Superintendent: The insulators loved it (not putting on the polyethylene). They thought it was the greatest thing since ice cream. They probably saved two or three hours. I would think they saved enough time to offset the putting on of the gasket along the bottom.

Monitoring Consultant: In the basement did you find any joists that were skewed, causing some difficulty in fitting the drywall around the joists, and consequently leaving large gaps between the joist and drywall?

Construction Superintendent: These were quite good. Generally, the drywallers did a good job and were careful. At the most, the gaps were 0.25 inches (6 MM)

Monitoring Consultant: Do these rafters ever twist at all after a few years?

Construction Superintendent: They basically should not because they are screwed on the top, they are cast in place. The only thing I could see is that they might shrink slightly, but I don't think that they would twist. With the flexible caulking, no gaps should open up.

Monitoring Consultant: What other caulking did you do in the house?

Construction Superintendent: Yes, where plumbing stacks went through the roof, any wires where we made a special blocking, around electrical outlets, and also around the windows. We used the same type of caulking.

Monitoring Consultant: Can you see any speed-ups in caulking the basement?

Construction Superintendent: No, I think that 4 to 5 hours is a fairly close estimate. It took us between 15 and 20 (small) tubes of caulking. I took my time and made it neat for the show home. We had to use small tubes because the big guns don't give much room, and there were some tight areas to caulk up in the joists. There were also some places where you had to put some sealant on a putty knife and jam it up tight.

Monitoring Consultant: Do you think that the caulking is easy enough for regular trades to do?

Construction Superintendent: Yes, just about anybody could do it. The painter could do it, the drywaller could do it, or just a general labourer. It is basically straight forward.

Another big thing was the gasket strip that we used between the bottom plate and the basement floor on the inside framing of the basement wall. We have a guy who does all our basement walls. He did the gasket. It was easy to do.

8. Interview with Don Brakken, superintendent

Monitoring Consultant: Having been involved in several ADA houses now, can you suggest improvements you would like to see incorporated into the system?

Superintendent: I think using the sill gasket for the drywall is the best way to go - it gives the best seal. But it must be continuous. If there are chunks of it missing you're better off not to use it. Because of its thickness,with some of it missing, the air just pours through there. You're better just to screw the drywall directly to the plate.

Monitoring Consultant: Can you see this system being adopted in a bigger way by the building industry?

Superintendent: Any builder, even a shoddy builder, could probably achieve R-2000 standards with this system. If you want to have the air test come in consistently at .4 or .5 then that takes a great deal more dedication. I would say 50 percent of the builders in Edmonton right now, once they'd built a couple of them probably get .7 - .8 consistently right now. I'm sure that 40 percent of the rest could achieve R-2000 standards and 10 percent would just never make it.

Monitoring Consultant: Is there anything you would like to add?

Superintendent: I really believe that with the ADA approach and the way we are doing it that within six months from now, we will consistently be able to bring these homes in at .4 air changes per hour at 50 pascals.

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